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THE UREDINALES OF ALASKA AND ADJACENT PARTS OF CANADA

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Received October 30, 1951

When the writer arrived in Alaska in 1914 he immediately started collecting plants. Most attention was paid to the vascular plants, but the other groups were not entirely neglected. In 1924 specimens of the non-vascular groups numbered more than 1,100, mostly parasitic fungi. In November, 1924, this collection was destroyed by fire. All these records were not lost, however. In the earlier years the writer corresponded with the late Dr. J. C. Arthur of Purdue University, and all the earlier determinations were made by him. Many of the Alaska records by Dr. Arthur in his Manual of the Rusts of the United States and Canada (3) were based on specimens sent him by the writer. In 1923 collections were made for the Bureau of Plant Industry of the United States Department of Agriculture. The record of these collections was made by Edith K. Cash in *Plant Disease Reporter* (5).

Collecting was resumed in 1925, and most of the data in this paper are based on specimens in the writer's herbarium now permanently deposited at Iowa State College at Ames.

After the publication of Arthur's Manual of the Rusts of the United States and Canada, the writer made his own determinations, or if in doubt, he sent specimens to Dr. G. B. Cummins of Purdue University. The three species of rust not known from North America at the time of publication of Arthur's Manual were determined by Dr. Cummins.

The nomenclature here used is that followed in Arthur's Manual. I, II, III indicate the aecial, uredial, and telial stages.

MELAMPSORACEAE

Uredinopsis struthiopteridis Störmer.

II, III. On *Athyrium filix-femina* (L.) Roth. Juneau, Ketchikan.

Milesia laeviuscula (D. & H.) Faull.

II, III. On *Polypodium vulgare* var. *occidentale* Hook. Sitka, Gull I. in Lynn Canal, Eagle R. near Juneau.

Hyalopsora aspidiotis (Peck) Magn.

II, III. On *Dryopteris linnaeana* C. Chr. Juneau, Tenakee, Haines.

Hyalopsora polypodii (Pers.) Magn.

II, III. On *Cystopteris fragilis* (L.) Bernh. Sitka, Lake Kluane.

Pucciniastrum alaskanum Mains.

II, III. On *Gentinana glauca* Pall. McKinley Park.

Pucciniastrum arcticum (Lagerh.) Tranz.

II, III. On *Rubus alaskensis* Bailey. Curry, Talkeetna. On *Rubus arcticus* L. Nash Hbr. on Nunivak I., Nome, Talkeetna Mts., Little Susitna R., Chickaloon, Hope. On *Rubus chamaemorus* L. Alaska. On *Rubus stellatus* Smith. Seward, Moose Pass and Hunter on Alaska R.R., Little Susitna R., Unalaska, Juneau, Chichagof I.

Pucciniastrum goeppertianum (Kuhn.) Kleb.

I. On *Abies lasiocarpa* (Hook.) Nutt. Rancheria, Yukon.

II, III. On *Vaccinium ovulifolium* Smith. Skagway. On *Vaccinium vitis-idaea* L. Skagway. On *Vaccinium uliginosum* L. Skagway.

Puccinastrum myrtilli (Schm.) Arth.

II, III. On *Vaccinium alaskense* Howell. Endicott R., Eagle R. near Juneau, Sitka, Haines, Ketchikan. On *Vaccinium caespitosum* Michx. Juneau, Ketchikan, Sitka. On *Vaccinium ovalifolium* Smith. Juneau, Ketchikan, Skagway, Sitka. On *Vaccinium uliginosum* L. Talkeetna, Unalaska.

Pucciniastrum pustulatum (Pers.) Diet.

I. On *Abies lasiocarpa* (Hook.) Nutt. Skagway. II, III. On *Epilobium angustifolium* L. Fairbanks, Haines, Matanuska, Takotna, Skagway, Wiseman. On *Epilobium glandulosum* Lehm. Juneau, Ketchikan, Sitka, Tenakee. On *Clarkia elegans* (cult.) Juneau. On *Godetia grandiflora* (cult.) Juneau. On *Fuchsia speciosa* (cult.) Juneau.

Pucciniastrum pyrolae (Pers.) Schroet.

II, III. On *Pyrola asarifolia incarnata* (DC.) Fern. Alaska. On *Pyrola minor* L. Hyder, Skagway. On *Pyrola secunda* L. Talkeetna and var. *obtusata* Turcz. Rancheria in Yukon.

Pucciniastrum sparsum (Wint.) Fisch.

II, III. On *Arctostaphylos alpina* L. Wiseman and on var. *rubra* (Fern.) Rhed. & Wils. Circle, Fairbanks, Franklin, Richardson Highway 86.

Melampsorella cerastii (Pers.) Schroet.

I. On *Picea glauca* (Moench) Voss. Circle Hot springs, Fairbanks, Healy, Sheep Mt., Wiseman. On *Picea mariana* (Mill.) B.S.P. Alaska Highway at White R., Franklin. On *Picea sitchensis* (Bong.) Roem. Glacier Pt., Haines.

II, III. On *Cerastium arvense* L. Cooper's Landing on Kenai Penin. On *Cerastium beeringianum* C. & S. Hope, Skagway. On *Stellaria longipes* Goldie. Alaska. The aecial stage on the spruces is very conspicuous and quite generally distributed over interior Alaska and Yukon.

Melampsoridium betulinum (Pers.) Kleb.

II, III. On *Betula glandulifera* Michx. Healy, Livengood. On

Betula kenaica W. H. Evans. Talkeetna. On *Betula papyrifera occidentalis* (Hook.) Hult. Juneau. On *Betula resinifera* Britt. Fairbanks, Franklin, Sheep Mt. On *Betula* hybrids. Haines, Takotna, Unalakleet.

Cronartium coleosporioides (D. & H.) Arth.

I. On *Pinus contorta* Dougl. Juneau, Haines, Skagway.

Cronartium comptoniae Arth.

II, III. On *Myrica gale* L. Ketchikan.

Chrysomyxa arctostaphyli Diet.

Microcyclic. On *Arctostaphylos uva-ursi* (L.) Spreng. Southern Yukon.

Chrysomyxa cassandrae (P. & C.) Tranz.

I. On *Picea mariana* (Mill.) B.S.P. Talkeetna.

II, III. On *Chamaedaphne calyculata* (L.) Moench. Fairbanks, Franklin, Matanuska.

Chrysomyxa empetri (Pers.) Schroet.

II. On *Empetrum nigrum* L. Liberty Falls (Edgerton Highway 10), Sheep Mt., Watson Lake. The host is very common but the rust is not.

Chrysomyxa ledicola (Peck) Lagerh.

I. On *Picea glauca* (Moench) Voss. Circle, Fairbanks, Franklin, Richardson Highway 86, 146 and 249, Wiseman. On *Picea mariana* (Mill.) B.S.P. Healy. On *Picea sitchensis* (Bong.) Carr. Juneau, Ketchikan.

II, III. On *Ledum decumbens* (Ait) Lodd. Nash Hbr. on Nunivak I., Cleary Summit (Steese Highway 21). On *Ledum groenlandicum* Oeder Circle, Chickaloon, Cooper's Landing, Juneau, Ketchikan, Richardson Highway 92 and 146, Willow, Wiseman, Sheep Mt. This rust is very common and widespread.

Chrysomyxa pyrolae (DC.) Rostr.

I. On *Picea sitchensis* (Bong.) Carr. Eagle R. near Juneau.

II, III. On *Moneses uniflora* (L.) Gray. Glacier Bay, Hope, Hyder, Slana-Tok Highway 12, Tenakee. On *Pyrola asarifolia incarnata* (DC.) Fern. Herbert R. near Juneau, Hyder, Rancheria (Alaska Highway 710), Seward, Unalaska. On *Pyrola minor* L. Valdez. On *Pyrola secunda* L. (and var. *obtusata* Turcz.) Alaska Highway at White R., Haines, Lake Kluane, Matanuska, Skagway. On *Pyrola chlorantha* Sw. Matanuska. Common on the *Pyrolaceae*. The aecial stage is found on the cone scales of spruce and not often collected.

Chrysomyxa roanensis Arth.

II, III. On *Rhododendron lapponicum* L. Alaska Highway between Ft. Nelson and the Liard R., B.C.

Coleosporium solidaginis (Schw.) Thüm.

II, III. On *Erigeron peregrinus* (Pursh) Greene. Juneau. On *aster subspicatus* Nees. Ketchikan. On *Solidago multiradiata* Ait. Livengood. On *Solidago* sp. Haines.

Melampsora albertensis Arth.

II, III. On *Populus tacamahacca* Mill. Fairbanks. On *Populus tremuloides* Michx. Fairbanks, Wiseman.

Melampsora arctica Rostr.

I. On *Saxifraga bracteata* D. Don. Savoonga.

II, III. On *Salix arctica* Pall. Point Hope. On *Salix fuscescens* Anders. Alaska. On *Salix glauca glabrescens* Anders. Deering. On *Salix polaris* Wahl. Alaska. On *Salix pulchra* Cham. Cape Lisburne, Nome. On *Salix chamissonis* Anders. Alaska. On *Salix sitchensis* Bong. Juneau. On *Salix* sp. Haines, Nome.

Melampsora bigelowii Thüm.

I. On *Larix laricina* (DuRoi) Koch. Richardson Highway 287.

II, III. On *Salix arbusculoides* Thum. Franklin, Gakona. On *Salix arctica* Pall. Juneau. On *Salix barclayi* And. Hope, Juneau. On *Salix glauca* L. and var. Unalakleet, Deering. On *Salix ovalifolia camdensis* Schn. Point Lay. On *Salix phlebophylla* And. Wiseman. On *Salix pulchra* Cham. Barrow, Kivelina, Unalakleet. On *Salix reticulata* L. Juneau, Tin City, Wiseman. On *Salix sitchensis* Bong. Juneau. On *Salix rotundifolia* Trauttv. Cape Lisburne, Point Lay, Talkeetna Mts. *Salix* sp. Circle, Healy, Juneau, Kivelina, Matanuska, Wiseman.

Melampsora lini (Pers.) Lev.

On *Linum perenne lewisii* (Pursh) Hult. Gakona, Lake Kluane, Richardson Highway 240.

Melampsora ribesii-purpureae Kleb.

I. On *Ribes triste* Pall. Hope.

PUCCINIACEAE

Tranzschelia subfusca (Holw.) Arth.

Autoeceous. On *Anemone patens multifida* (Pritzel) Zamels. Globe (on Livengood Highway), Healy, Lignite, Matanuska.

Phragmidium alaskanum (Arth.) Syd.

On *Rubus stellatus* Smith. Yakutat Bay.

Phragmidium andersoni Shear. *Phragmidiums* are all autoeceous.

On *Potentilla fruticosa* L. Circle, Franklin.

Phragmidium montivagnum Arth.

On *Rosa woodsii* Lindl. Circle Hot Springs.

Phragmidium occidentale Arth.

On *Rubus parviflorus* Nutt. Haines, Juneau, Sitka, Tenakee.

Phragmidium potentillae (Pers.) Karst.

On *Potentilla pennsylvanica* L. and var. *strigosus* Pursh. Fairbanks, Franklin, Tanacross.

Phragmidium rosae-acicularis Liro.

On *Rosa acicularis* Lindl. Cooper's Landing (Kenai Penin.) Copper Centre, 52 mi. east of Fairbanks, Healy, Hope, Knik, McKinley Park, Takotna, Haines. On *Rosa nutkana* Presl. Haines, Sitka. On *Rosa rugosa* hybrids Sitka. This species is very common and widespread.

Phragmidium rosae-californicae Dietl.
On *Rosa acicularis* Lindl. Talkeetna. On *Rosa nutkana* Presl. Endicott R. on Lynn Canal.

Phragmidium rubi-idaei (DC.) Karst.
On *Rubus arcticus* L. Northway. On *Rubus stellatus* Smith. Atka I. On *Rubus strigosus* Michx. Curry, Talkeetna.

Phragmidium subcorticum (Schr.) Wint.
On *Rosa rugosa* hybrid Juneau.

Xenodochus carbonarius Schl.
On *Sanguisorba officinalis* L. Sitka.

Xenodochus minor Arth.
III. On *Sanguisorba sitchensis* C. A. Mey. Kodiak I., Talkeetna Mts. Report of this species on *Sanguisorba microcephala* was erroneous.

Gymnoconia peckiana (Howe) Trotter.
On *Rubus arcticus* L. Stebbins, St. Michael, Takotna. On *Rubus pubescens* Raf. Liard Hot Springs.

Nyssopsora echinata (Lev.) Arth.
Microcyclic. On *Oenanthe sarmentosa* Presl. Goddard Hot Springs on Baranof I. Report on *Coelopleurum* was an error.

Puccinia adoxae Hedw.
Microcyclic. On *Adoxa moschatellina* L. Hope, Palmer.

Puccinia angelicae (Schum.) Fckl.
Autoeceous. On *Angelica genuflexa* Nutt. Eagle R. near Juneau.

Puccinia arenariae (Schum.) Wint.
Microcyclic. On *Arenaria lateriflora* L. Circle, Matanuska, Takotna. On *Arenaria physodes* Fisch. Circle. On *Stellaria longipes* Goldie. Alaska.

Puccinia areolata D. & H.
Autoeceous. On *Caltha biflora* DC. Craig, Ketchikan. On *Caltha palustris asarifolia* (DC.) Hult. Matanuska. On *Caltha leptosepala* DC. Talkeetna Mts.

Puccinia arnicalis Peck.
II, III. On *Arnica louiseana frigida* (Mey.) Mag. Globe (on Livengood Highway), Healy, Wiseman.

Puccinia artemisiae-norvegicae Tranz.
III. On *Artemisia arcica* Less. Wiseman.

Puccinia bistortae (Str.) DC.
I. On *Angelica lucida* L. Unalaska.
II, III. On *Polygonum bistorta plumosum* (Small) Hult. Franklin, Takotna, Wiseman. On *Polygonum viviparum* L. Eagle R., Juneau, Nome, Unalaska, Wiseman.

Puccinia bupleuri Rud.
I. On *Bupleurum americanum* C.& R. Franklin.

Puccinia caricis grossulariata Arth.
I. On *Ribes alpinum* L. (cult.) Sitka. On *Ribes bracteosum* Dougl. Hyder, Juneau, Sitka, Tenakee. On *Ribes hudsonianum*

Rich. Fairbanks. On *Ribes lacustre* (Pers.) Poir. Gull I. (Lynn Canal), Sitka. On *Ribes laxiflorum* Pursh. Hyder, Juneau. On *Ribes sanguineum* Pursh (cult.) Sitka. On *Ribes triste Poll.* On *Ribes vulgare* Lam. (cult.) Sitka.
II, III. On *Carex macochaeta* Mey. Juneau, Sitka. On *Carex mertensii* Prescott. Haines, Juneau, Sitka. On *Carex pleuriflora* Hult. Alaska. On *Carex sitchensis* Prescott. Sitka.

Puccinia caricis urticata (Kern) Arth.
I. On *Urtica lyallii* Wats. Juneau.

Puccinia cicutae Lasch.
Autoeceous. On *Cicuta douglasii* (DC.) C.&R. Haines.

Puccinia circaeae Pers.
Microcyclic. On *Circaea alpina* L. Echo Cove (Lynn Canal), Juneau, Ketchikan, Sitka, Talkeetna.

Puccinia coelopleuri Arth.
Autoeceous. On *Angelica lucida* L. *Coelopleurum gmelini* (DC.) Ledeb. Eagle R. near Juneau, Echo Cove (Lynn Canal), Haines, Hope, Juneau, Seward. Probably an endemic.

Puccinia conglomerata (Str.) S. & K.
Microcyclic. On *Petasites frigidus* (L.) Fries. Barrow, Talkeetna Mts., Wainwright. On *Petasites palmatus* (Ait.) Gray Rancheria (Alaska Highway 710).

Puccinia coronata Cda.
I. On *Shepherdia canadensis* (L.) Nutt. Alaska Highway at White R., Fairbanks, Franklin, Healy, Ketchikan, Whitehorse.
II, III. On *Calamagrostis canadensis* (Michx.) Beauv. Wiseman. On *Deschampsia caespitosa* (L.) Beauv. Watson Lake.

Puccinia cruciferarum Rud.
Microcyclic. On *Cardamine bellidifolia* L. Talkeetna Mts.

Puccinia drabae Rud.
Microcyclic. On *Draba aurea* Vahl. Skagway.

Puccinia extensicola Plowr.
I. On *Erigeron peregrinus* (Pursh) Greene. Unalaska.

Puccinia fergussoni B. & Br.
Microcyclic. On *Viola epipsila repens* (Turcz.) W. Bkr. Hope. On *Viola langsdorfii* Fisch. Juneau.

Puccinia gemella D. & H.
Microcyclic. On *Caltha leptosepala* DC. Southeast Alaska.

Puccinia gentianae (Str.) Link.
Autoeceous. On *Gentiana algida* Pall.

Puccinia gigantea Karst.
Microcyclic. On *Epilobium angustifolium* L. Circle.

Puccinia gigantispora Bubak.
Autoeceous. On *Anemone multifida* Poir. Chitina, Gakona, Lake Kluane.

Puccinia grumosa Syd. & Holw.
Autoeceous. On *Zygadenus elegans* Pursh. Cooper's Landing (Kenai Penin.), Franklin, Watson Lake.

Puccinia gymnandrae Tranz.

III. On *Lagotis glauca Gaertn.* Nash Harbor (Nunivak I.).

Puccinia heucherae (Schw.) Diet.

Microcyclic. On *Heuchera glabra* Willd. Cordova, Haines, Ivanof Bay, Juneau, Seward, Skagway. On *Mitella pentandra* Hook. Douglas, Hyder, Talkeetna Mts. On *Saxifraga lyallii* Engler. Talkeetna Mts. On *Tellima grandiflora* (Pursh) Dougl. Ivanof Bay. On *Tiarella trifoliata* L. Sitka, Tenakee. On *Tiarella unifoliata* Hook. Juneau. On *Tolmiea menziesii* (Pursh) T. & G. Craig.

Puccinia hieracii (Schum.) Mart.

Autoeceous. On *Hieracium albiflorum* Hook. Hyder. On *Taraxacum* ssp. Anchorage, Haines, Fairbanks, Skagway, Talkeetna, Valdez, Whitehorse, Wiseman.

Puccinia holboellii (Hornem.) Rostr.

Microcyclic. On *Arabis holboelli* and var. *retrofracta* (Grah.) Rydb. Chickaloon, Cooper's Landing (Kenai Penin.), Fairbanks, Gakona, Matanuska, Rancheria (Alaska Highway 710), Tanacross, Whitehorse. On *Arabis lyrata kamtschatica* (Fisch.) Hult. Eagle Cr. (Steese Highway), Hope, Juneau, Seward.

Puccinia insperata Jacks.

Autoeceous. On *Prenanthes alata* (Hook.) Dietrich. Ketchikan, Sitka.

Puccinia karelica Tranz.

I. On *Trientalis europea arctica* (Fisch.) Hult. Juneau.

Puccinia laurentiana Trel.

Microcyclic. On *Saxifraga nudicaulis* D. Don. St. Lawrence I.

Puccinia leveillei Mont.

Microcyclic. On *Geranium erianthum* DC. Cooper's Landing, Juneau, Talkeetna Mts., Unalaska.

Puccinia ligustici E. & E.

Microcyclic. On *Conioselinum benthami* (Wats.) Fern. Amchitka I., Gull I. (Lynn Canal), St. Paul I.

Puccinia linkii Klotzsch

Microcyclic. On *Viburnum edule* (Michx.) Raf. Matanuska, Seward, Skagway.

Puccinia menthae Pers.

Autoeceous. On *Monarda mollis* L. Yukon. Reported in Arthur's Manual. No Monarda is know from Yukon.

Puccinia mertensiana Peck.

Microcyclic. On *Mertensia paniculata* Ait. Clearwater Creek at Slana-Tok Highway.

Puccinia mesomajalis B. & C.

Microcyclic. On *Clintonia uniflora* (Schult.) Knuth. Hyder, Ketchikan.

Puccinia millefolii Fckl.

Microcyclic. On *Achillea borealis* Bong. Haines. On *Artemisia tilesii* and varieties. Franklin, Healy, Lake Kluane. On *Artemisia laciniata* Willd. Globe (Livengood Highway).

Puccinia nephrophyllidii described by Mains (6) as occurring on *Nephrophyllidium crista-galli* (Menz.) Gilg. collected by D. W. Baxter at Ketchikan, Alaska in 1938, is probably only *Puccinia areolata* D. & H. on *Caltha biflora* DC. The leaves of *Nephrophyllidium* and *Caltha biflora* are so similar that even an expert could not with certainty tell them apart. This was impressed on the writer on seeing both species growing together intermixed on a small muskeg near Ketchikan. The only way he could be certain was after the inflorescence appeared. *Puccinia areolata* is common on the *Caltha* but in many years of botanizing in Alaska the writer has found no rust on *Nephrophyllidium*. It is his firm conviction that this was a case of mistaken identity of the host. Compare descriptions of *P. areolata* and *P. nephrophyllidii*.

Puccinia obscura Schroet.

II, III. On *Luzula multiflora* Retz. Eagle R. near Juneau.

Puccinia ortonii Jacks.

Autoeceous. On *Dodecatheon frigidum* C. & S. Haines, Lignite. On *Dodecatheon macrocarpum* (Gray) Knuth. Juneau. On *Dodecatheon viviparum* Greene. Annette I., Juneau, Ketchikan.

Puccinia oudemansii Tranz.

Microcyclic. On *Parrya nudicaulis* (L.) Regel. Cape Lisburne.

Puccinia oxyriae Fckl.

II, III. On *Oxyria digyna* (L.) Hill. Juneau.

Puccinia palmeri D. & H.

Autoeceous. On *Pentatemon procerus* Dougl. Teslin Lake, Whitehorse.

Puccinia parkerae D. & H.

Microcyclic. On *Ribes lacustre* (Pers.) Poir. Chatham.

Puccinia pimpinellae (Str.) Mart.

Autoeceous. On *Osmorrhiza chilense* Hook. & Arn. Klukwan.

Puccinia poarum Niels.

I. On *Petasites frigidus* (L.) Fr. Kotzebue, Lignite, Richardson Highway 152 and 233, St. Paul I., Stebbins. On *Petasites hyperboreus* Rydb. Eagle R. near Juneau. On *Petasites sagittatus* (Banks) Gray. Northway.

Puccinia poa-sudetica (Westend.) Jorstad.

II, III. On *Poa pratensis* L. Juneau

Puccinia polemonii D. & H.

Microcyclic. On *Polemonium acutiflorum* Willd. Gambell.

Puccinia polygoni-alpini Cruch & May.

II, III. On *Polygonum alaskanum* (Small) Wight. Golovin, Unalakleet.

Puccinia porphyrogenita Curt.

Microcyclic. On *Cornus canadensis* L. Craig, Echo Cove (Lynn

Canal), Eagle R. near Juneau, Haines, Juneau, Ketchikan, Tenakee. On *Cornus suecica* L. Juneau.

Puccinia pulsatillae Kalchb.

Microcyclic. On *Anemone narcissiflora* L. Richardson Highway 207. On *Anemone parviflora* Michx. Wiseman. On *Anemone patens multifida* (Pritzl) Zamels. Healy.

Puccinia pygmaea Erikss.

II, III. On *Arctagrostis latifolia arundinacea* (Trin.) Griseb. Alaska Highway near Canadian border. On *Calamagrostis nutkaensis* (Michx.) Beauv. Sitka.

Puccinia ranunculi Blytt.

Microcylic. On *Ranunculus eschscholtzii* Schlecht. Sitka.

Puccinia retecta Syd.

Microcyclic. On *Anemone narcissiflora* L. Cleary Summit (Steese Highway 20), Healy, Juneau, Takotna, Unalaska.

Puccinia rubifaciens Johans.

Microcyclic. On *Galium boreale* L. Circle, Fairbanks, Healy, Wiseman.

Puccinia rubigo-vera (DC.) Wint. var. **agropyri** (Erikss.) Arth.

I. On *Aconitum maximum* Pall. Igitkin I., St. Paul I. On *Aconitum delphinifolium* DC. St. Paul I. On *Aquilegia formosa* Fisch. Cooper's Landing (Kenai Penin.), Gull I. (Lynn Canal), Juneau. On *Ranunculus cymbalaria* Pursh. Matanuska. On *Ranunculus occidentalis* Nutt. Unalaska. On *Thalictrum hultenii* B. Boivin. Unalaska. On *Actaea arguta* Nutt. Cooper's Landing, Klukwan.

II, III. On *Elymus mollis* Trin. Alaksa. On *Elymus virescens* Piper. Alaska. On *Trisetum spicatum* (L.) Richt. Talkeetna.

Puccinia septentrionalis Juel.

I. On *Thalictrum alpinum* L. Alaska.

II, III. On *Polygonum viviparum* L. Juneau.

Puccinia swertiae Wint.

Autoeceous. On *Swertia perennis* L. Isabella Pass.

Puccinia syphoricarpi Hark.

Microcyclic. On *Symphoricarpus rivularis* Suksd. Klukwan.

Puccinia uliginosa Juel.

I. On *Parnassia palustris* L. Kodiak I.

Puccinia vagans (DC.) Arth. var **epilobi-tetragoni** DC.

Autoeceous. On *Epilobium angallidifolium* Lam. Talkeetna Mts. On *Epilobium glandulosum* Lehm. Juneau.

Puccinia veratri (DC.) Duby.

I. On *Epilobium anagallidifolium* Lam. Talkeetna Mts. On *Epilobium latifoium* L. Talkeetna Mts. On *Epilobium* sp. Ketchikan.

Puccinia violae (Schum.) DC.

Autoeceous. On *Viola adunca* J. E. Sm. Haines. On *Viola epipsila repens* (Turcz.) W.Bkr., Hyder, Juneau, Sitka. On

Viola glabella Nutt. Echo Cove (Lynn Canal), Ketchikan. On *Viola langsdorfii* Fisch. Eagle R. near Juneau, Juneau, Skagway. On *Viola renifolia brainardii* (Greene) Fern. Chickaloon. On *Viola* sp. Talkeetna.

Puccinia volkartiana Fisch.

Microcyclic. On *Androsace chamaejasne lehmanniana* (Spreng.) Hult. Rapids Lodge (Richardson Highway 233).

Uromyces caryophyllinus (Schr.) Wint.

II, III. On *Dianthus carophyllinus* L. (cult.) Juneau.

Uromyces fabae (Pers.) deBary

Autoeceous. On *Lathyrus maritimus* (L.) Bigel. Haines, Matanuska, Unalakleet.

Uromyces geranii (DC.) Fries.

Autoeceous. On *Geranium erianthum* DC. Cooper's Landing (Kenai Penin.), Echo Cove (Lynn Canal), Haines, Ivanof Bay, Juneau, Palmer, Unalaska.

Uromyces hedysari-obscuri (DC.) Car. & Picc.

Autoeceous. On *Hedysarum alpinum americanum* Michx. Alaska Highway at White R., Endicott R., Healy, Lake Kluane, Matanuska, Mayo, Watson Lake, Wiseman. On *Hedysarum mackenzii* Rich. Gakona, Whitehorse, Wiseman.

Uromyces lapponicus Lagerh.

Autoeceous. On both subspecies of *Oxytropis nigrescens* (Pall.) Fisch. Healy, Twelve Mile Summit (Steese Highway 87), Unalakleet. On *Oxytropis gracilis* (A. Nels.) K. Schm. Burwash.

Uromyces miurae Syd.

Microcyclic. On *Fritillaria camtschatcensis* Ker. Hope, Hyder, Juneau.

Uromyces phacae-frigidae (Wahl.) Hariot.

Microcyclic. On *Astragalus umbellatus* Bunge. Eagle Summit (Steese Highway 109), Wiseman.

Uromyces polygoni (Pers.) Fckl.

Autoeceous. On *Polygonum buxiforme* Small. Haines, Palmer, Seward.

Uromyces solidaginuis (Sommerf.) Niessl.

Microcyclic. On *Solidago* sp. Hot Springs on Liard R.

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I. On *Sorbus scopulina* Greene. Takotna. On *Sorbus sitchensis* Roem. Alaska.

Gymnosporangium juniperinum (L.) Mart.

I. On *Sorbus sitchensis* Roem. Haines.

Gymnosporangium nelsoni Arth.

I. On *Amelanchier alnifolia* Nutt. Carcross. On *Malus fusca* Raf. Ketchikan.

II, III. On *Juniperus horizontalis* Moench. Carcross.

Gymnosporangium nootkatense (Trel.) Arth.

I. On *Malus fusca* Raf. Sitka. On *Sorbus sitchensis* Roem. Sitka.

II, III. On *Chamaecyparis nootkatensis* (Lamb.) Spach. Craig, Sitka.

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GROWTH STUDIES OF THE CARP, *CYPRINUS CARPIO* LINNAEUS, IN CLEAR LAKE, IOWA[1]

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For several years the Iowa State Conservation Commission has maintained a rough fish removal program to reduce the numbers of carp, *Cyprinus carpio* Linnaeus, in Clear Lake. The present investigation was initiated to study the growth rate, life history, and changes in abundance of the Clear Lake carp. Most of the data were collected in the summer of 1950, but scales and measurements were also available from 93 carp collected in 1941, 1943, and 1947–49. These earlier specimens were taken mostly with experimental gill nets; most of the 1950 specimens were taken by seines.

Clear Lake is a shallow, eutrophic lake with a maximum depth of 20 feet and a total area of 3,643 acres. The lake is divided into two main areas, the eastern and western, by a long bar extending from McIntosh Woods State Park to Lone Tree Point. During the summer of 1950 the lake was less than 35 yards wide at that point. The eastern end is the deeper and has little rooted aquatic vegetation; most of the western end is less than 8 feet deep. In 1945 and 1946 the western end was choked with pond weeds and bulrushes, but in 1949 and 1950 the aquatic vegetation was very sparse.

Two marshes adjoin the main body of the lake. The larger marsh is at the western end of the lake, south of the town of Ventura. The marsh is isolated from the lake by a road grade, but water may flow from the marsh into the lake during periods of high water. The second marsh, smaller than the Ventura Marsh, is at the southeastern end of the lake. It dries up during some summers, but retained some water from June through September of 1950.

Evidence of successful carp reproduction in 1950 was encountered only in the Ventura Marsh. Many young carp could be obtained in

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the marsh, but intensive seining in the main body of the lake failed to capture any young-of-the-year carp.

Carp were observed during spawning activities in the marsh in the southeast corner of the lake and in a small stream flowing into the northern side of the western area of the lake. However, no young-of-the-year carp could be found in or near those two areas.

The Iowa State Conservation Commission operates a carp trap at the entrance to the Ventura Marsh. Water flows over a dam through the trap and into the main body of the lake. Thousands of pounds of carp were removed from the trap, most of which were fish on their way to spawn in the marsh. Some carp did spawn in Ventura Marsh, however, and the young-of-the-year were very abundant. There was little direct evidence of the larger brood fish, however, and probably very few got past the trap.

Despite extensive sampling, no young carp were taken in Clear Lake proper in 1950. The biologists of the Cooperative Fisheries Research

TABLE 1

TOTAL LENGTHS IN INCHES OF YOUNG CARP IN VENTURA MARSH, 1950

Date	Number	Mean Length	Range
July 28	36	2.7	1.7–3.7
August 1–2	125	3.0	2.2–6.0
August 13–15	113	4.0	2.2–7.2
September 24	30	5.1	3.0–6.3

Unit took one young carp in the lake proper in 1947, and two in 1949. The lake survey crew of the Biology Section of the State Conservation Commission report taking 92 young carp in 1945, 23 in 1946, but none from the same areas in 1947 through 1950. Apparently carp have not spawned successfully in Clear Lake proper for four years. Research Unit biologists report finding young carp at several points in the lake in 1951, however.

The young carp grew quite rapidly in the Ventura Marsh and by the end of the summer were over 5 inches long (Table 1). All lengths in this report are total lengths. To convert to fork lengths, multiply by 0.907, or to convert to standard length, measured to the end of the vertebral column, multiply by 0.800. The first conversion factor is based upon measurements of 325 carp from 7 to 32 inches long, the second on 154 carp in the same size range. There was some evidence that the tail becomes proportionately shorter as the fish grows, but the conversion factors for small and large carp did not differ by more than 2 per cent.

It has been established that the length-weight relationship of fish is described satisfactorily by the formula:

$W = cL^n$

where W is the weight, L the length, and c and n are constants. When

the weights and lengths are transformed to logarithms, the relationship is linear:

$$\text{Log } W = \text{Log } c + n \text{ Log } L.$$

An analysis of covariance (Table 2) indicated that the slopes of the length-weight regressions for male and female carp were so similar as to be considered identical. Comparison of the weights (Table 3) suggested that the females were usually heavier for their length than the males. A test of significance for differences in adjusted mean weights, similar to that used by Mottley (5), indicated the females were heavier for their lengths than the males (Table 4). The length-weight relationships were therefore computed for the sexes separately:

Male: $\text{Log } W = -1.02258 + 2.74598 \text{ Log } L.$

Female: $\text{Log } W = -0.98164 + 2.74598 \text{ Log } L.$

where W = weight in hundredths of a pound

and L = total length in inches.

The factor C is used to express the condition, or relative plumpness, of fish weighed and measured in the English system. In reality C is an expression of body form, but can be interpreted to yield various informa-

TABLE 2

Analysis of Covariance and Test of Significance of the Hypothesis That the Length-Weight Regression Coefficient Is the Same for Male and Female Carp, Clear Lake, 1950*

Source of Variation	Degrees of Freedom	Sums of Squares and Products		
		Sl^2	Slw	Sw^2
Male	132	1.710,387,72	4.677,505,75	13.013,543,37
Female	164	1.601,771,56	4.417,607,38	12.458,459,11
Total	296	3.312,159,28	9.095,113,13	25.472,002,48

Source of Variation	Errors of Estimate		
	Sum of Squares	Degrees of Freedom	Mean Square
Male	.221,671,80	131	
Female	.274,914,68	163	
Male & Female	.496,586,48	294	.001,686,59
Total	.497,031,26	295	
Diff. for testing	.000,444,78	1	.000,444,78

$$F = .000,444,78/.001,689,07 = .2633$$

* The system of notation is similar to that used by Snedecor (9). Sl^2 indicates the sum of the squares of the deviations from the mean length. Slw indicates the sum of the products of the deviations from the mean length and mean weight. Sw^2 indicates the sum of the squares of the deviations from the mean weight. F is the variance ratio, the significance of which is evaluated according to the distribution discovered by R. A. Fisher.

TABLE 3

MEAN TOTAL LENGTHS IN INCHES AND MEAN WEIGHTS IN POUNDS OF CARP FROM CLEAR LAKE, 1950, ARRANGED IN ONE-INCH GROUPS

Males (133)			Females (165)		
Mean Total Length	Number of Specimens	Mean Weight	Mean Total Length	Number of Specimens	Mean Weight
7.60	1	.25		0	
8.55	2	.39		0	
	0		9.55	2	.50
10.55	1	.69	10.15	2	.62
11.35	2	.81	11.30	1	.81
12.75	2	1.12	12.35	2	.97
	0		13.20	1	1.25
14.50	2	1.53	14.25	2	1.47
15.61	17	1.76	15.61	8	1.99
16.40	39	2.16	16.56	27	2.32
17.20	10	2.36	17.52	52	2.75
18.20	7	2.97	18.45	26	3.18
19.10	2	3.44	19.25	10	3.53
20.55	2	4.10	20.10	1	3.50
21.00	2	4.25	21.10	1	4.13
22.45	5	4.60		0	
23.55	6	5.66	23.55	2	6.72
24.33	7	5.82	24.30	1	6.31
25.53	10	6.63	25.46	5	6.76
26.40	3	7.19	26.42	6	8.13
27.40	7	8.50	27.77	3	10.65
28.27	3	10.94	28.20	1	19.88
29.35	2	12.19	29.72	5	12.11
30.00	1	11.37	30.10	2	12.72
	0		31.40	1	12.56
	0		32.60	4	14.99

tion such as the physical condition of an individual or population. suitability of a given habitat, or time of spawning.

The formula used in computing C was:

$$C = \frac{1000W}{L3}$$

where W is weight expressed in hundredths of a pound and L is total length expressed in inches.

The average coefficients show a tendency to decrease with increase in the age and size of the fish (Table 5). The length-weight regression indicated that the weight increased at a rate less than the cube of the length and that the C values should therefore decrease. The greater weight of the females than males at similar lengths shows up only in the higher C values for the females of the II and III age groups.

The first critical use of fish scales for the study of growth was by Hoffbauer in 1898–1900 on carp (10). Carp scales show many checks and false annuli and are rather difficult to use for age determination.

TABLE 4

ANALYSIS OF COVARIANCE AND TEST OF SIGNIFICANCE OF THE HYPOTHESIS THAT THE ADJUSTED MEAN WEIGHTS FOR MALE AND FEMALE CARP, CLEAR LAKE, 1950, ARE THE SAME

Source of Variation	Degrees of Freedom	Sums of Squares and Products		
		Sl^2	Slw	Sw^2
Sex	1	0.000,065,34	−.002,657,38	0.108,076,16
Within Sex	296	3.312,159,28	9.095,113,13	25.472,002,48
Total	297	3.312,224,62	9.092,455,75	25.580,078,64

Source of Variation	Errors of Estimate		
	Sum of Squares	Degrees of Freedom	Mean Square
Within Sex	.497,031,21	295	.001,684,85
Total	.620,191,97	296	
Diff. for testing	.123,160,76	1	.123,160,76

$$F = .123,160,76/.001,684,85 = 73.10^{**}$$

Many scales from the Clear Lake samples had to be discarded because they were abnormal in form or were regenerative.

Young-of-the-year carp could be readily recognized because of their small size (Table 1) and because of the isolated habitat in which they were found. No annulus was evident on the scales of those fish. The next larger size group, 8 to 13 inches long, had one quite distinct annulus, with cutting-over or anastomosis evident in the lateral field and with a very different spacing of the circuli during the first year's growth compared to that of the circuli formed during the ensuing summer. The annulus apparently is formed prior to June 15, as all carp collected in 1950 already had formed an annulus for the year.

The age of 2- and 3-year-old carp was established with little difficulty, but on the older fish it was more difficult to determine which were valid annuli. Anastomosis of the circuli on the lateral field was considered the best criterion. The largest carp, 38.2 inches long and 37.4 pounds in weight, was believed to be between 9 and 11 years old, but the center and lateral fields of the scale were such that more accurate determination of the age was impossible.

The body-scale relationship for 285 carp collected in 1950 was examined and the best fitting straight line determined by the least squares method (Table 6). The equation (Length = 0.0269 inches + 2.451 radius) overestimates the lengths from 11 through 19 inches and underestimates the lengths over 26 inches, but a more complicated curve is not believed to be justified by the data. The lengths at various annuli were therefore computed on a direct proportion basis.

TABLE 5

AVERAGE COEFFICIENTS OF CONDITION FOR CLEAR LAKE CARP

Age Group	Sex	Year of Collection	Number of Specimens	Mean C Value
I	.....	1947	7	53.7
	Male	1950	6	57.5
	Female	1950	8	55.0
II	.....	1948	36	48.4
	.....	1949	20	47.8
	Male	1950	72	46.6
	Female	1950	114	50.7
III	Male	1950	29	39.0
	Female	1950	14	44.9
IV	Male	1950	6	45.5
	Female	1950	11	43.6
V	Female	1950	2	48.5
VI	Female	1950	1	45.0

The calculated growth rates (Table 7) indicate that the second summer is the time when carp grow most rapidly, both in length and weight. The growth in Clear Lake appears to be faster than that reported for carp in Minnesota (1, 8) or in Tennessee (3, 6). No consistent differences in the growth rates of males and of females were noted.

The carp collected in 1947–1949 showed a somewhat slower growth than those collected in 1950, even when compared to fish of the same year class (Table 8). The earlier collections were all taken in the eastern end of the lake, while most of those taken in 1950 were taken from the western end. In 1950, 9 carp of age group II were taken from the eastern end of the lake. These had an average calculated length at the first annulus of 6.13 inches compared to a calculated length of 7.04 inches at the first annulus of 176 carp of age group II taken from the western end. The growth rates in the two areas of the lake appear to be different unless a one in 20 chance in sampling occurred (Table 9). It is possible that there are two more or less isolated populations in the lake, one probably spawning in Ventura Marsh and the other in the small marsh at the southeast corner of the lake.

All carp collected from the main body of Clear Lake were examined to determine their stage of sexual development. If on moderate pressure eggs or milt were extruded, the carp was considered to be ripe. If a fish was not ripe it was opened, the sex noted, and the condition of the gonad observed.

No yearling carp showed any evidence of being ripe or having spawned previously. However, yearling females had eggs developing in their ovaries. From the degree of development it was concluded that

TABLE 6

MEAN TOTAL LENGTHS AND MEAN ANTERIOR SCALE RADII (X175) MEASURED IN INCHES OF CLEAR LAKE CARP COLLECTED IN 1950, ARRANGED IN ONE-INCH SIZE GROUPS

Number of Specimens	Mean Length	Mean Radius	Computed Length*
1	7.60	2.40	5.91
2	8.55	3.55	8.73
3	9.60	3.72	9.15
2	10.40	4.15	10.20
3	11.33	4.63	11.38
3	12.43	5.47	13.44
1	13.20	6.00	14.74
5	14.48	6.36	15.62
26	15.62	6.70	16.45
70	16.47	6.90	16.94
64	17.43	7.30	17.92
29	18.42	7.70	18.90
10	19.25	8.11	19.90
2	20.55	8.35	20.50
3	21.33	8.70	21.35
3	22.40	9.30	22.82
7	23.60	9.66	23.71
6	24.33	9.55	23.44
14	25.54	10.35	25.40
9	26.41	10.98	26.94
6	27.40	10.75	26.38
4	28.25	10.92	26.79
5	29.68	11.26	27.62
2	30.00	11.95	29.32
1	31.40	11.10	27.23
4	32.60	12.15	29.81

* Length = 0.0296 inches + 2.451 radius.

the yearling females would have been capable of spawning the following spring.

All the 2-year-old and older carp were ripe or appeared to have been capable of spawning. The last record of a ripe female was made on July 7. Therefore, that date is considered to be relatively close to the last date carp were capable of spawning in 1950. Milt could be stripped from an occasional male carp for a few weeks longer, but since it is probable that no ripe females were present, the ability or inability of the milt to fertilize eggs at that late date is of little importance.

In the course of examining the sexual development of Clear Lake carp, evidence was encountered that indicated that some fish capable of spawning failed to do so in 1950. Since the time of spawning can be more readily ascertained by examination of female fish, the conclusions are based almost solely on the observed sexual condition of the female carp.

As previously mentioned, the last ripe female carp was taken on July 7. On that day two fish were stripped into a spawning box and the eggs fertilized with milt from two male carp. Whereas the eggs

TABLE 7

CALCULATED AND MEASURED TOTAL LENGTHS IN INCHES OF 113 MALE AND 150 FEMALE CARP COLLECTED FROM CLEAR LAKE, JUNE 17–JULY 28, 1950

Age Group	Number* Examined	Length at Capture	Average Calculated Length at Each Annulus					
			1	2	3	4	5	6
I	M 6	10.00	6.38					
	F 8	11.14	6.80					
II	M 72	16.75	7.17	15.39				
	F 114	17.50	6.88	15.57				
III	M 29	25.27	9.79	19.70	23.59			
	F 14	23.99	9.02	17.65	21.97			
IV	M 6	28.48	9.47	19.97	24.68	27.20		
	F 11	29.39	9.87	20.30	25.34	27.93		
V	M ..	.....	.....	.....	.....	.....	.....	
	F 2	31.10	9.60	19.70	23.60	27.15	29.90	
VI	M ..	.....	.....	.....	.....	.....	.....	.....
	F 1	32.80	11.80	20.80	24.70	27.60	29.40	31.40
Mean total length		Male	8.20	18.35	24.14	27.20	.....	.....
		Female	8.90	18.81	23.90	27.56	29.65	31.40
Annual length increment		Male	8.20	9.54	4.30	2.52	.....	.....
		Female	8.90	9.38	4.29	3.01	2.27	2.00
Average† weight		Male	0.33	2.89	5.95	8.26	.....	.....
		Female	0.48	3.37	6.40	9.40	11.50	13.46
Annual weight increment		Male	0.33	2.50	2.48	1.94	.....	.....
		Female	0.48	2.84	2.63	2.54	2.29	2.23

* M = male and F = female.

† Weights are given in pounds and hundredths, calculated from the length-weight equations:

$$\text{Male Log } W = -1.02258 + 2.74598 \text{ Log } L.$$
$$\text{Female Log } W = -0.98164 + 2.74598 \text{ Log } L.$$

usually "hatch in 10 to 20 days, depending on the temperature" (2), the eggs in the hatching box were eyed in less than 24 hours and hatched in less than 96 hours. The water temperature was 71° F. in the lake, where the hatching box was moored.

Many of the female carp examined after July 7 had ovaries that were full of eggs. The eggs had lost the orange translucency observed earlier and were darker, more opaque, and quite hard. It is believed, therefore, that at least some of the female carp failed to deposit their eggs in 1950, resorbing the eggs as the season progressed.

Of the carp collected in 1950, 55 were examined for possible

parasites and internal disease. In addition to those carefully examined, an abnormality of any carp in the entire sample was recorded.

A parasitic tapeworm (*Caryophyllaeus* sp.) was observed in the digestive tract of 14 carp. The infestation varied in intensity from a few parasites present in the digestive tract to one observation of more than 50 of the cestodes in a single carp. The parasite apparently caused

TABLE 8

COMPARISON OF CALCULATED GROWTH IN INCHES OF CARP FROM CLEAR LAKE COLLECTED DURING FOUR SUMMERS

Year of Sample	Number of Specimens	Year of Birth	Age at Capture	Calculated Total Length		
				I	II	III
1950	43	1947	III	9.54	19.03	23.06
1949	20	1947	II	6.44	14.43	.....
1950	17	1946	IV	9.73	20.18	25.11
1948	37	1946	II	6.26	13.95	.....
1947	7	1946	I	6.84	.....	.....

TABLE 9

A TEST OF THE HYPOTHESIS THAT THE CALCULATED GROWTH OF TWO-YEAR-OLD CARP DURING THE FIRST YEAR WAS SIMILAR IN THE EASTERN AND WESTERN AREAS OF CLEAR LAKE

Area of Capture	Degrees of Freedom	Mean Growth in Inches	Sum of Squares	Mean Squares
Western	176	7.04	56.92	0.3234
Eastern	8	6.13	10.60	1.3250

"Theoretical" $t_{.05} = 2.241$ *

$$t = \frac{0.91}{0.386} = 2.356$$

* Since the variances appeared to differ significantly, a method proposed by Cochran and Cox (9, pp. 83–84) was used for the t test.

little harm to the host carp, all of which appeared normal otherwise. No parasites of the flesh, gills, or body organs were observed.

Two deformed fish were examined. One fish had a stunted caudal peduncle and the other had a pronounced spinal curvature. The lower lobe of the caudal fin of one carp was missing.

The most marked abnormality was a soreness about the mouth observed in many of the carp examined. Originally, the reddened and raw areas were believed due to the methods of capture and of holding the fish. Many of the fish had parts of the mouth missing and several had the flesh rotted to such an extent that bones of the jaw were visible.

All the injury was attributed to damage while in the net and carp trap and from overcrowding in the holding boxes in the lake.

Later, however, carp with similar sores were taken in gill nets in the eastern area of the lake. Four carp were captured in gill nets in the last week of July which showed evidence of the sore and rotting areas about the mouth. Two of the fish still showed open sores and prominent reddened areas. One of the fish was partially healed, and the remaining fish had healed completely, with only scars left to indicate the previous condition.

It was believed that some other structure might be used to determine the age and growth of carp more accurately and easily than the scales. Sections of the dorsal spine appeared to be satisfactory for fish up to 2 years old but were difficult to interpret on older fish. The opercle, however, gave promise of being more satisfactory than scales. LeCren (4) used the opercle in studying the age and growth of the European perch, *Perca fluviatilis* L.

The left opercle of 151 carp was removed for examination. The bone was removed from the fish by grasping the posterior margin of the opercle, tearing the dorsal connection loose forward to the point of articulation, then tearing downward. In that manner the opercle and subopercle were freed from the carp. Twisting the opercle outward while tearing it loose aided in removing some of the flesh from the bone. A similar twisting motion used in removing the subopercle resulted in the removal of even more flesh and cartilage from the bone. With practice the opercle could be removed with very little flesh adhering to it. The opercles were stored in scale envelopes.

Cleaning was begun by dipping the opercle into boiling water. The opercle was allowed to remain for about one minute in the vigorously boiling water, and then was removed and scoured with a toothbrush. By using two containers, a single operator was able to complete the preparation of approximately 45 opercles in an hour, a speed not attained with either the scales or spines.

The opercles were examined from the concave and convex surfaces in both transmitted and reflected light to effect each age determination. The change of light revealed rings and areas of varying translucency and reflectivity on each opercle (Fig. 1 and 2). There was a roughened area on the concave surface of all opercles which is believed to correspond to the growth in the summer of collection, and which was, therefore, a useful criterion of the most recent annual mark.

The opercle of a young-of-the-year carp is characterized by a uniformly rough concave surface, small size, lack of bulk, and no single outstanding ring. All opercles examined from carp captured in the Ventura Marsh were similar to the description given above. No fish in their first summer of life were recognized in the sample from the main body of the lake on the basis of the opercle method.

The opercle of a yearling carp shows a smooth area on the concave surface, corresponding to the growth during the period before formation

of the first annual mark. The growth of the carp after the formation of the first annulus is recorded on the concave surface of the opercle as a roughened area, similar to the entire concave surface of a young-of-the-year carp. A definite change in thickness can also be observed, the opercle being markedly thinner outside the year mark.

The growth of the first year is still readily apparent on the opercle of a 2-year-old carp. The first year's growth is bounded by a translucent area sharply circumscribed by an extremely opaque area. The area inside the first year mark is the most opaque general area on the opercle. The second year mark is recognized by the combination of a translucent and an opaque area, as is the first annulus. In addition, the growth inside the second annulus is marked by an increased thickness over the growth outside the year mark. Further, the growth of the summer of collection is marked by a roughened area, similar to that already described.

A similar procedure is used to estimate the age of older fish. A combination of the same criteria — change in thickness, change in opacity, combination of highly translucent and opaque areas adjoining one another, and roughness near the edge — appears to reveal definitely the age of carp by the opercle method. On the opercles of older fish it was found desirable to examine the convex surface closely, as the true year marks seemed more prominent and accessory markings less visible when viewed in that manner.

A difficulty is encountered in attempting to calculate the past growth of the larger fish. The fingers of bone growing out onto the concave surface, supporting the socket, almost obscure the growth of the first year. Again, an examination of the convex surface is most helpful, but may be inexact in fish longer than 32 inches in total length. It is assumed that the supporting fingers of bone continue to increase in length at a similar rate in older and larger fish, but it seems unlikely that more than the first year of growth would ever be obscured if the fish continue to grow at a rate similar to that observed in this study.

A simple technique allows calculation of past growth on a nomograph, similar to the calculation employed with the scale method. The age is marked on the opercle on the concave surface, outlining the annuli in pencil. The opercle is slipped beneath a glass plate elevated about ½ inch above the table. The center of the socket, each annuli, and the edge of the opercle can then be accurately recorded on a strip of paper. The body-opercle relationship was found to fit a straight line better than did the body-scale relationship.

The ages as determined by the opercle and the scale method agreed on all young-of-the-year, yearling, and 2-year-old carp. The opercle method established 6 fish as 4-year-olds. Two of the fish had been aged as 4-year-olds by the scale method. Four of the fish could not be aged by the scale method. Therefore, the opercle method resulted in a considerable increase in data. The opercle method established 23 carp as 3-year-olds. Of that group, 12 had been aged as 3-year-olds by the

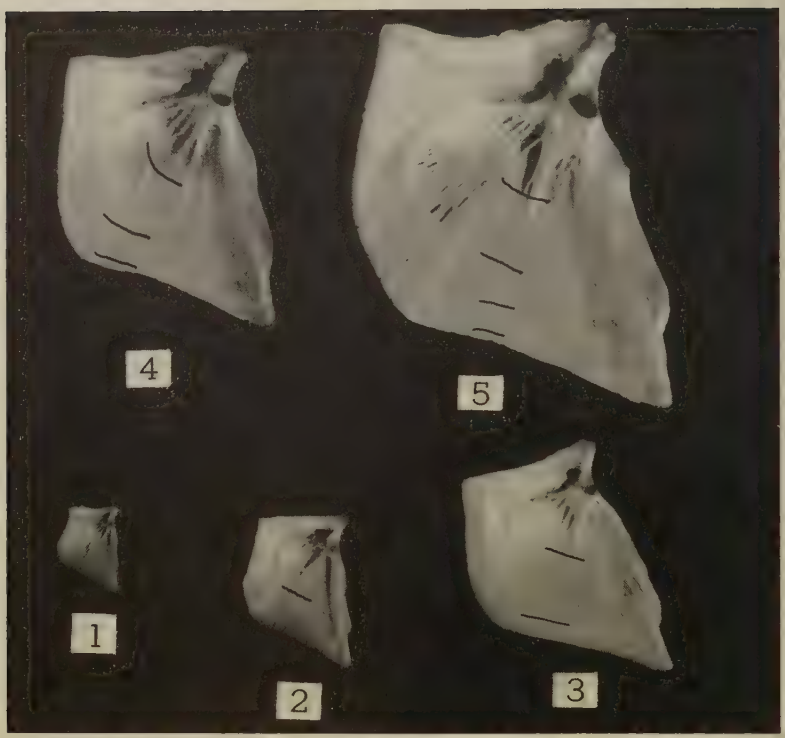

FIG. 1. Opercles from carp collected in Clear Lake and the Ventura Marsh. Photographed by reflected light. Annuli are indicated in black. The scales and spines of these fish are illustrated in preceding sections.

1. Young-of-the-year carp. Collected in the Ventura Marsh on August 2, 1950. Total length, 5.9 inches.
2. Yearling carp. Collected in Clear Lake on July 15, 1950. Total length, 11.3 inches.
3. Two-year-old carp. Collected in Clear Lake on July 28, 1950. Total length, 18.5 inches.
4. Three-year-old carp. Collected in Clear Lake on June 24, 1950. Total length, 23.3 inches.
5. Four-year-old carp. Collected in Clear Lake on July 14, 1950. Total Length, 32.8 inches.

scale method, 3 had been incorrectly aged as 4-year-olds, and 8 could not be aged using the scale method. It is believed that the ages as determined by the opercle method are more nearly accurate than those determined by the scale method.

The subopercle was also examined for use in age and growth studies, but was found unsuitable. The subopercle, although smaller and easier to remove, clean, and store than the opercle, does not show evidence of annual differentiation as does the opercle.

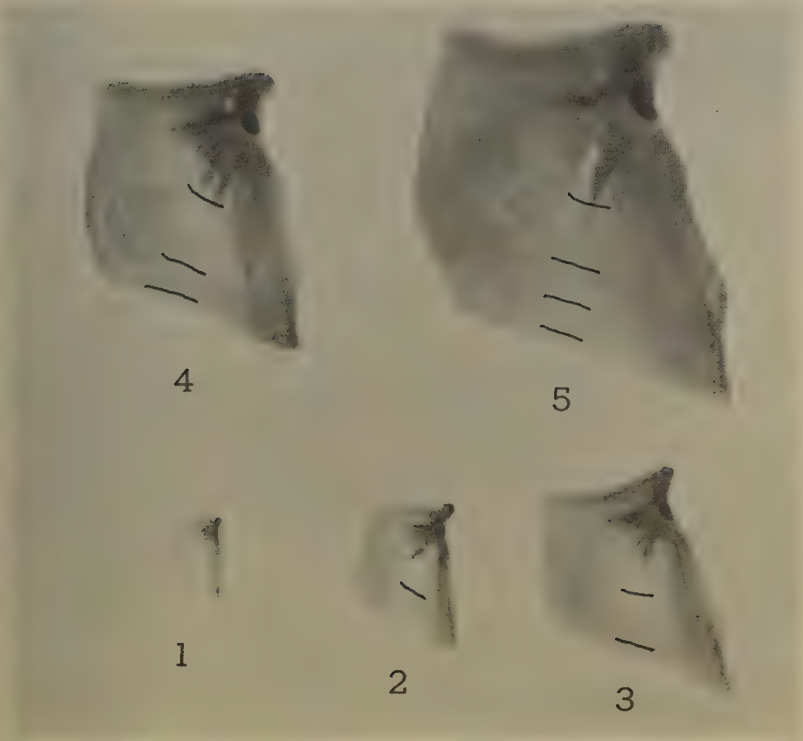

FIG. 2. Opercles from carp collected in Clear Lake and the Ventura Marsh. Photographed by transmitted light. Annuli are indicated in black. The scales and spines of these fish are illustrated in preceding sections.

1. Young-of-the-year carp. Collected in the Ventura Marsh on August 2, 1950. Total length, 5.9 inches.
2. Yearling carp. Collected in Clear Lake on July 15, 1950. Total length, 11.3 inches.
3. Two-year-old carp. Collected in Clear Lake on July 28, 1950. Total length, 18.5 inches.
4. Three-year-old carp. Collected in Clear Lake on June 24, 1950. Total length, 23.3 inches.
5. Four-year-old-carp. Collected in Clear Lake on July 14, 1950. Total Length, 32.8 inches.

SUMMARY

1. A bar virtually divides Clear Lake into an eastern and a western area. A marsh adjoins each area.

2. In 1950 young carp were found only in the Ventura Marsh. Intensive sampling indicates that the carp did not spawn very successfully in Clear Lake proper from 1947 through 1950.

3. The average length conversion factors are 0.800 for changing total length to standard length and 0.907 for changing total length to

fork length. Statistical anaylsis indicated that the females were heavier for their length than the males. The relationships between length in inches and weight in hundredths of a pound for the sexes are:

$$\text{Log } W = -1.02258 + 2.74598 \text{ for males,}$$
$$\text{Log } W = -0.98164 + 2.74598 \text{ for females.}$$

The average coefficient of condition, C, was 48.

4. Clear Lake carp increased the most in length and weight during their second summer, adding an annual increment of over 9 inches and 3 pounds for that year.

5. There is evidence of two more or less separate populations in the lake with those in the western end growing more rapidly.

6. Clear Lake carp appear to become capable of spawning when they reach 2 years of age. However, some 2-year-old and older female carp apparently failed to spawn in 1950.

7. A parasitic cestode of the family Caryophyllaeidae was observed in the digestive tract of some carp. A sore and reddened area was observed about the oral region of many of the carp examined and appeared to be a pathological condition.

8. An examination of the opercles indicated that they may reveal the age and past growth of carp more accurately than do the scales. The subopercle and cross-sections of the dorsal spine did not give satisfactory results.

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CONTROLLED WATERFOWL HUNTING ON A STATE-OWNED PUBLIC SHOOTING GROUND, FORNEY LAKE, IOWA, 1950[1]

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Because of the continuing increase in the number of waterfowl hunters and the continuing loss of waterfowl habitat to agriculture and other uses, the problem of providing sportsmen with an opportunity to harvest waterfowl has become acute in recent years. Waterfowl hunters, as indicated by the sale of duck stamps in the nation, have increased from 635,001 in 1934 to 1,722,677 in 1948, an increase of almost 200 per cent (5). In Iowa only 50,000 acres remain of the approximately 6,000,000 acres of waterfowl habitat used by waterfowl for nesting and rearing purposes prior to 1900 (2). These two factors have served to concentrate hunting pressure on limited areas, and, in many instances, have resulted in their loss as productive hunting units.

To accommodate the increasing waterfowl hunting group, wildlife administrators and managers have focused their attention on the acquisition and development of public shooting grounds. With the aid of funds from the Pittman-Robertson Federal Aid to Wildlife Restoration Act of 1938, the 14 states of the Mississippi Flyway had acquired 102 public shooting grounds comprising 305.635 acres by 1950. This figure does not include the 90,171 acres of public shooting area under the supervision of the U. S. Fish and Wildlife Service. In Iowa the State Conservation Commission has provided 68 public shooting grounds for its hunters (1). Some of these hunting areas, particularly those near large population centers, are subjected to large concentrations of duck hunters during the waterfowl hunting season. Acute competition for space to hunt and for shots at waterfowl has resulted in poor sportsmanship and low hunting success.

One such area, the Forney Lake Game Refuge and Public Shooting Ground, is located in extreme southwestern Iowa near Thurman, Fremont County. It is one of the most popular waterfowl shooting areas in the state and is extensively utilized. Most of the hunting pressure is contributed by Council Bluffs, Iowa, only 40 miles away, but hunters

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from as far away as Des Moines, Iowa, a distance of about 175 miles, utilize the area each fall.

Forney Lake, the remnant of an old oxbow lake of the Missouri River, is a cattail-bulrush marsh of 869 acres, of which approximately 489 acres are open to public hunting. The refuge part of the Forney Area is densely covered with cattail (*Typha latifolia* L.) and three-square bulrush (*Scirpus americanus* Pers.). About 80 per cent of the public shooting ground is covered with American lotus (*Nelumbo pentapetala* Walt.) during the spring and summer months. Scattered sparse islands of cattail are located on the public shooting ground, but they afford little cover during the fall and winter months. Because of the intense hunting pressure, poor hunting conditions, and low hunting success, the Iowa State Conservation Commission inaugurated a controlled hunting system on the Forney Lake public shooting ground during the 1950 waterfowl hunting season. This management program was evaluated in part by the Iowa Cooperative Wildlife Research Unit.

MANAGEMENT PLAN

The Forney Lake public shooting ground was changed to a managed shooting ground. It remained subject to state and federal regulations pertaining to licenses, duck stamp, bag limits, shooting hours, and methods of taking migratory waterfowl. Special regulations were designed to accomplish three objectives: (1) limit the number of hunters on the area at any one time, (2) distribute them over the area to decrease crowding and competition, and (3) give all licensed hunters an equal opportunity to utilize the area.

Twenty-five three-man blinds were constructed of rough lumber and were anchored on the hunting area (Fig. 1). The blinds were built on four floating oil drums. They were spaced on the lake so that each was situated in an estimated 10 acres of shooting territory. As they were designed to accommodate three men, the number of hunters on the area at any one time was limited to a maximum of 75. No persons other than the conservation officers and hunters occupying the blinds were permitted on the shooting ground. Hunting was from the blinds only.

To give all persons an equal opportunity to hunt on the managed area, reservations were given to applicants on a first-come-first-serve basis. These reservations were issued at the Conservation Commission's Des Moines office from September 15 to October 15. After October 15, they were issued at the Forney Area headquarters. Reservations were given to parties of two or three men and not to individual hunters. Two hunting dates were given each party. Applicants were asked to specify four dates on which they wished to hunt. When possible, the two dates given each party were assigned from their four choices. Each party's reservations and a sheet of instructions and general information regarding the managed area were mailed to them.

A state conservation officer was appointed to manage the area, and five other officers from neighboring counties were detailed at different

periods to aid him. In addition to the area manager, at least one conservation officer was present until the opening of pheasant hunting season, November 11, 1950. The principal duty of the assisting officers was to enforce the area regulations.

A check station was maintained at the headquarters building. All hunters with or without reservations were required to report in and out at this building. Parties with reservations were required to be present at the station one hour and fifteen minutes prior to the opening hour of shooting. At that time, the area manager issued a hunting permit to each party with a reservation. Hunting licenses and duck stamps were

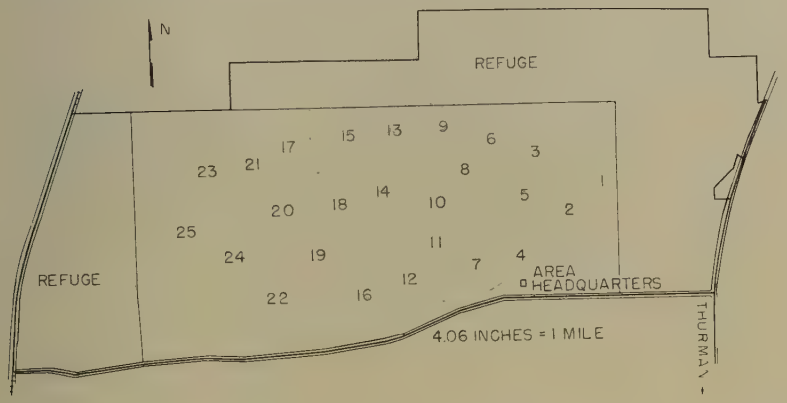

FIG. 1. Approximate locations of the refuge boundaries and blind sites, Forney Area, 1950.

taken from all hunters to insure that they checked out at the station. Assignment to specific blinds was accomplished by using a drawing. When parties failed to claim their reservations, the available blinds were given to others who had no reservations. The area manager kept a list of hunters without reservations as they reported to the station. When more hunters were present than the available blinds could accommodate, those from the top of the list were assigned first. As blinds became vacant during the day, other hunters were assigned to them.

When the parties left the area, they turned in their hunting permits and retrieved their hunting licenses and duck stamps. Hunting bags were checked for species composition, and the waterfowl were sexed and aged by cloacal examination.

HUNTING PRESSURE

A total of 1,704 hunters, grouped into 700 parties, utilized the managed shooting ground (Table 1). A mean number of 20.0 parties with an average of 2.43 men per party hunted on the area each day. Inasmuch as it was possible for 2,625 sportsmen to schedule appointments and hunt on the area, hunting pressure was less than the potential for the

managed area. The potential hunting accommodations, 2,625 sportsmen, were computed by multiplying the daily hunting capacity (75 men) by the length of the hunting season (35 days). As it was possible for others to hunt after hunters with reservations vacated their blinds, the potential hunter capacity of the area was even greater. Use of the managed

TABLE 1

DAILY HUNTING PRESSURE AND WATERFOWL HARVEST, FORNEY AREA, 1950

Date	Number of Parties	Number of Hunters	Harvest
October 20	25	65	17
" 21	24	63	89
" 22	26	70	30
" 23	17	41	8
" 24	20	50	69
" 25	21	49	49
" 26	16	38	42
" 27	15	34	49
" 28	23	60	38
" 29	26	66	18
" 30	14	32	18
" 31	9	23	28
November 1	15	37	49
" 2	26	54	39
" 3	20	49	41
" 4	31	77	21
" 5	32	79	24
" 6	27	64	55
" 7	34	80	50
" 8	34	81	59
" 9	27	71	138
" 10	13	29	56
" 11	5	13	45
" 12	12	30	31
" 13	8	19	5
" 14	14	33	25
" 15	26	64	38
" 16	26	62	32
" 17	17	37	45
" 18	25	64	39
" 19	28	71	53
" 20	11	25	37
" 21	3	7	5
" 22	21	46	51
" 23	9	21	24
Total	700	1,704	1,417
Mean	20.0	48.7	40.5
Range	3–34	7–81	5–138
Standard Deviation	±8.27	±20.87	±24.4

shooting ground in 1950 amounted to 64.9 per cent of the computed hunter capacity.

Examination of the number of parties that used their reservations further illustrated the under-utilization of the area. All reservations were filled by October 27, 1950. Of the 875 issued, 382 (43.7 per cent)

of the parties used them, while 493 (56.3 per cent) did not. In addition, 318 parties hunted without making previous appointments. This factor of low reservation use was important since it assured those hunters without reservations an opportunity to hunt. On 17 (48.5 per cent) of the days, as many or more hunters hunted without reservations than those who hunted with previous appointments. With the exception of the opening half-day, when blinds were not available for six or seven requests, no unscheduled hunters were turned away. On a few occasions hunters had to wait until a party checked out, but their wait was usually not more than 45 minutes.

It became evident as the season progressed that the sportsmen were utilizing the area as often as they wished. For example, three groups of hunters involving 12 persons hunted on the area a total of 33 times. This example serves to illustrate that the managed or controlled area acted not as a method of reducing hunting pressure, but as a method of distributing the pressure throughout the hunting season. Had the demand for hunting space been in excess of the area's potential daily hunting capacity, the hunting opportunity or privilege would have been reduced.

To evaluate the importance of the Forney Area to the entire state and to determine the origin of the hunting pressure, residences of the hunting parties were recorded from the hunters' hunting licenses. The hunters resided in 40 cities in 20 counties of Iowa and two cities of Nebraska (Table 2). Though most of the parties came from southwestern Iowa, some came from central, northwest, and southeast Iowa. Council Bluffs contributed 58.2 per cent of the parties. Parties from Omaha, Nebraska, made up only 6.2 per cent of the 700 hunting groups.

HUNTING SUCCESS

All but three of the 700 hunting parties were contacted in determining hunting success. Two of the three parties failed to check out at the check station. The third party was probably missed when several parties returned from hunting at the close of shooting hours.

Waterfowl of 21 species were harvested during the hunting season. Of 1,417 waterfowl brought to bag, 1,301 were ducks, 91 were coot, and 25 were geese (Table 3). The harvest averaged 0.83 birds per man day, and the mean time required to harvest one bird was 7.66 hours. All of the 1,417 waterfowl that were harvested during the season were bagged by 57.3 per cent of the 700 hunting parties. Eighty-two (4.8 per cent) of the hunters shot daily limits of four ducks; none harvested limits of geese, mergansers, or coot.

Numbers of waterfowl were low during the first half of the season as compared with numbers during the last half. During the first half of the season, the hunters' bags consisted mainly of the early-migrant species of pond ducks. These were blue-winged teal (*Anas discors* Linnaeus), pintail (*Anas acuta tzitzihoa* Vieillot), green-winged teal (*Anas carolinensis* Gmelin), baldpate (*Mareca americana* [Gmelin]), and mallard (*Anas platyrhynchus platyrhynchus* Linnaeus). A cold wave on

TABLE 2

RESIDENCES OF HUNTING PARTIES ACCORDING TO COUNTIES AND CITIES, FORNEY AREA, 1950

Pottawattamie	
Council Bluffs	408
Oakland	11
Avoca	5
Minden	2
	426
Polk	
Des Moines	42
Fremont	
Bartlett	14
Thurman	13
Tabor	6
Farragut	1
Randolph	1
Riverton	1
	36
Montgomery	
Red Oak	28
Stanton	4
Villisca	3
	35
Taylor	
Bedford	7
Mills	
Malvern	10
Pacific Junction	7
Glenwood	4
Silver City	3
Hastings	1
	25
Page	
Shenandoah	20
Clarinda	19
Essex	1
	40
Shelby	
Harlan	10
Defiance	2
Earling	1
	13
Carroll	
Templeton	5
Carroll	2
	7
Cass	
Atlantic	4
Griswold	1
	5
Story	
Ames	5
Warren	
Indianola	3
Adams	
Corning	2
Adair	
Fontanelle	1
Boone	
Boone	1
Buena Vista	
Newell	1
Greene	
Jefferson	1
Jasper	
Newton	1
Muscatine	
Wilton Junction	1
Pocahontas	
Pocahontas	1
Nebraska (state)	
Omaha	44
Fort Crook	3
	47

TABLE 3

WEEKLY HARVEST TOTALS OF WATERFOWL, FORNEY AREA, FALL, 1950

Species	Oct. 20–26	Oct. 27-Nov. 2	Nov. 3–9	Nov. 10–16	Nov. 17–23	Total	Per Cent
Mallard (*Anas platyrhynchus platyrhynchus* Linnaeus)	58	48	226	167	230	729	51.44
Pintail (*Anas acuta tzitzihoa* Vieillot)	39	27	10	1	1	78	5.50
Blue-winged teal (*Anas discors* Linnaeus)	58	5	2	.....	1	66	4.65
Green-winged teal (*Anas carolinensis* Gmelin)	27	16	9	7	3	62	4.37
Baldpate (*Mareca americana* [Gmelin])	16	14	11	3	1	45	3.17
Gadwall (*Anas strepera* Linnaeus)	8	16	28	3	.....	55	3.88
Shoveller (*Spatula clypeata* [Linnaeus])	17	5	12	22	6	62	4.37
Redhead (*Aythya americana* [Eyton])	7	15	26	11	.....	59	4.16
Lesser scaup (*Aythya affinis* [Eyton])	3	12	36	3	4	58	4.09
Ring-necked duck (*Aythya collaris* [Donovan])	11	13	8	.....	.....	32	2.25
Ruddy duck (*Erismatura jamaicensis rubida* [Wilson])	2	14	3	.....	2	21	1.48
Canvasback (*Aythya valisineria* [Wilson])	.....	2	4	6	.....	12	0.84
American golden-eye (*Glaucionetta clangula americana* [Bonaparte])	.....	.....	.....	.....	1	1	0.07
Wood duck (*Aix sponsa* [Linnaeus])	1	1	1	.....	2	5	0.35
American merganser (*Mergus merganser americanus* Cassin)	.....	.....	1	3	3	7	0.49
Hooded merganser (*Lophodytes cucullatus* [Linnaeus])	.....	1	.....	.....	.....	1	0.07
Coot (*Fulica americana americana* Gmelin)	41	44	6	.....	.....	91	6.42
Blue goose (*Chen caerulescens* [Linnaeus])	2	2	.....	.....	.....	4	0.28
Lesser snow goose (*Chen hyperborea hyperborea* [Pallas])	4	3	2	3	.....	12	0.84
Canada goose (*Branta canadensis*)	2	.....	3	3	.....	8	0.56
White-fronted goose (*Anser albifrons albifrons* [Scopoli])	.....	1	.....	.....	.....	1	0.07
Unidentified*	8	.....	.....	.....	.....	8	0.56
Totals	304	239	388	232	254	1,417	99.91

* The three bags containing these ducks were not checked by the observer. They were listed on the hunting permit forms as three teal, three bluebills, and two widgeon.

November 9, the first inclement weather of the season, precipitated the main flights of the mallard, lesser scaup (*Aythya affinis* [Eyton]), and redhead (*Aythya americana* [Eyton]). After this date concentrations of mallards varying in number from a few hundred to as many as 10,000 birds rafted in the northwest corner of the managed shooting ground. A concentration varying in numbers with new flights of birds was maintained on the area until the termination of the study.

A total of 32,980 mallards was counted between August 17 and December 17. Mallards, the chief components of the hunters' bags

TABLE 4
PRODUCTIVITY OF THE 25 BLINDS, FORNEY AREA, 1950

Blind	Parties	Harvest*	Birds per Party
1	25	44	1.76
2	22	28	1.27
3	30	47	1.57
4	14	18	1.28
5	41	174	4.24
6	35	85	2.43
7	19	12	0.63
8	31	52	1.68
9	28	56	2.00
10	32	67	2.09
11	27	46	1.70
12	21	26	1.24
13	29	62	2.14
14	26	49	1.88
15	28	68	2.43
16	26	32	1.23
17	30	54	1.80
18	34	70	2.06
19	20	34	1.70
20	31	77	2.48
21	32	48	1.50
22	25	33	1.32
23	31	58	1.87
24	29	61	1.10
25	34	95	2.79

* A mallard hen was shot from the shore by a party of hunters and is not included in the blind kill.

during the last three weeks of the hunting season, comprised 51.44 per cent of the total harvest. None of the other species of waterfowl approached the mallard in numbers, and none exceeded 6.42 per cent of the harvest.

Productivity of the 25 blinds varied greatly. Blind success ranged from 12 birds harvested at number 7 blind to 174 birds harvested at number 5 blind (Table 4). The variation may be explained in part by examining the number of hunting parties that utilized each blind. For

example, 41 parties hunted in number 5 blind and 19 parties hunted in number 7 blind. Comparison of the average party-kill of the two blinds indicated the presence of other factors. The parties hunting in number 5 blind averaged 4.24 birds per party day, while those in number 7 averaged 0.63 birds.

It appeared that the individual blind success was related more to the type of hunter, his ability, and his equipment than to any other apparent factor. The veteran waterfowl hunters who used large numbers of decoys and who permitted their birds to come within effective gun range usually were successful. The three groups of hunters who utilized the area 33 times were veteran hunters. Parties made up from the three groups used between 75 and 85 decoys. During their 33 hunts, members of the three groups harvested 212 waterfowl for a mean kill of 2.46 birds per man day. The success of these hunters was three times that of the other hunters.

Cover apparently had little effect on the individual blind success, for more waterfowl were harvested from some of the blinds situated in open water than from others placed in the sparse growths of cattail.

Success of the five blinds anchored near the south shore was lower than the success of the other 20. These five blinds, numbers 4, 7, 12, 16, and 22, were within 200 yards of a gravel road running parallel to the south shore (Fig. 1). The total harvest of these five blinds averaged 24.2 birds per blind while that of the other 20 averaged 64.8 birds. Human activity along the gravel road may have been responsible for the lower success. Birds returning from the cornfields south of the lake usually flew high over the road and were often beyond effective gun range for the blinds nearest the south shore. By contrast, birds approaching the lake from the north, west, or east had to pass over the refuge before reaching the managed shooting ground and were usually lower.

Crippling loss amounted to 20.9 per cent; i.e., for every four birds brought to bag, one was unretrieved. The harvest by the 579 parties interviewed in determining crippling loss was 1,249 retrieved birds, and the unretrieved number was 330. All waterfowl that were decisively hit and kept flying or that fell and could not be found were classed as cripples. As calculated from the sample obtained from the 579 parties, the total crippling loss amounted to 374 birds.

RELATIONSHIP OF HUNTING PRESSURE TO SUCCESS

Hunting pressure, when increased to a high level on a limited area, is itself a factor that results in decreased hunting success. To determine the effect that the number of hunters had on the harvest at the Forney Area, the data were analyzed statistically. A regression equation and correlation coefficient were calculated to illustrate the relationship of the number of hunters to the daily total harvest. This relationship was not found to be statistically significant ($r = 0.32$, .05 level for 33 d.f. $= 0.339$). The regression line, expressed by the equation $\hat{y} = 21.75 + 0.38475x$, had a positive slope (Fig. 2). Biological interpretation

of these data indicated that an increase in the number of hunters on the area did not result in a statistically significant increase in the total daily harvest.

Competition on the Forney Area was manifested by "sky shooting." Some hunters, anxious to harvest their share of the waterfowl, showed their zeal and impatience by taking long shots at birds. Sky shooting was more apparent on the area when hunters were near the maximum and waterfowl were relatively scarce. When a party began improper shooting practices, other parties often began also. Of 130 parties asked if they had noticed sky shooting on the area, 98 (75.4 per cent) complained

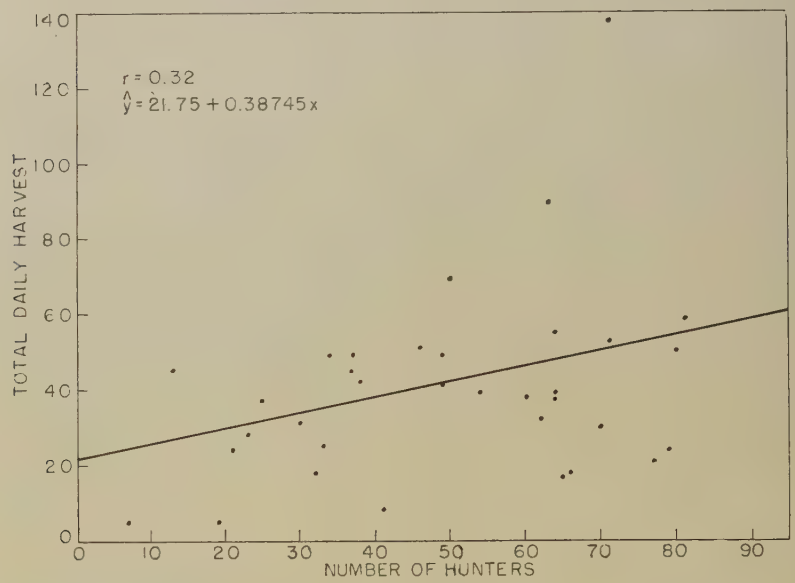

Fig. 2. Relationship of the number of hunters to the total daily waterfowl harvest, Forney Area, 1950.

that it had affected their harvest, 26 (20.0 per cent) noticed some but thought that the controlled area had decreased it as compared with former years, and 6 (4.6 per cent) noticed none.

Disturbance naturally increased as the number of hunters increased. Disturbance was caused mainly by hunters entering and leaving the shooting ground, setting out and rearranging decoys, breaking ice from in front of their blinds, and retrieving dead and crippled birds.

Promiscuous shooting of the less desirable species of waterfowl and of protected birds occurred to a limited extent. According to the conservation officer of Page and Fremont Counties, hunters in past seasons shot a great many coot and made no effort to retrieve them. The hunters that used the area in 1950 were warned against that practice. The

warnings undoubtedly discouraged the hunters from that type of shooting. Sportsmen shot a few protected birds, but those instances were for the most part the result of misidentifications. Promiscuous shooting was motivated on days of waterfowl scarcity.

HUNTER OPINIONS

Hunter opinions were solicited on four major points: (1) "Are you satisfied with the way the area is being managed?" (2) "Do you see any improvement over the old system of uncontrolled hunting?" (3) "Are you in favor of the area remaining controlled in subsequent years?" and (4) "What is your opinion of the blinds?"

Of 235 parties questioned, 211 (89.8 per cent) were satisfied with the way the area was being managed. Most of the dissatisfied 24 wanted to use some other type of blind. Only two (0.9 per cent) of the 235 parties saw no type of improvement over the old system of uncontrolled hunting, and 175 (86.6 per cent) of 202 parties were in favor of the area remaining controlled. The two greatest complaints of the hunters concerned the blinds and sky shooting.

Hunters from 199 parties commented on the blinds. While 109 (55.2 per cent) of the parties were satisfied with them, 90 (44.8 per cent) had a variety of complaints. Of those who were not satisfied, 34 (37.7 per cent) thought that they were too unstable, sank too low in the water, and thus hindered shooting. Twenty-three (25.5 per cent) thought that the blinds should have been constructed to conceal a boat, and 11 (12.2 per cent) complained that the sides were too high. Nine (10.0 per cent) complained of no blind seats, and eight (8.8 per cent) thought that the bulky blinds scared decoying ducks. The other five (5.5 per cent) had five different complaints about the blinds. These complaints ranged from one party wanting a rack for shotgun shells to another complaining of poor construction.

COST OF THE PROJECT

The total cost of the Forney Area project to the Conservation Commission was $2,415.37 (Table 5). The total represents a cost of $96.61 per blind, or $1.41 per hunter. As the blinds are permanent structures and are to be used on the area in subsequent years, all of the $2,415.37 should not be considered as expenses for 1950. Ice prevented removal of the blinds until the spring thaw of 1951. Some repair will be necessary, but the cost should not be great, as the blinds were sturdily constructed. Blind expenses for the waterfowl season of 1951 will include costs of repair, recovering them with slough grass, and towing them out and anchoring them on the lake.

A Conservation Commission news release (5) announced that a fee of 50 cents per person will be charged at the managed shooting ground in 1951. This fee should almost completely defray the cost of management and operation of the area. Faber (4) estimated the cost for 1951 to be about $1,500.

SUMMARY

1. Because of intense hunting pressure, poor hunting conditions, and low hunting success, the Iowa State Conservation Commission inaugurated a system of controlled hunting on the Forney Lake Game Refuge and Public Shooting Ground during the 1950 waterfowl hunting season. The management plan was evaluated in part by the Iowa Cooperative Wildlife Research Unit.
2. Twenty-five floating, three-man blinds were constructed and distributed over the 489-acre shooting ground. Hunting was permitted from the blinds only, and two dates were given each applicant requesting reservations.
3. A total of 1,704 hunters, grouped into 700 parties, harvested 1,417

TABLE 5
COST OF THE FORNEY AREA PROJECT, 1950

Administrative Costs	
Labor in processing 605 pieces of mail	$ 165.00
Area manager's salary	306.59
Construction Costs	
Blind materials	661.01
Labor in constructing the blinds	680.00
Transportation	287.77
Operational Costs	
Maintenance of the blinds	292.00
Printed matter (permit books, mimeographed instructions, reservation notices	23.00
	$2,415.37

waterfowl. The harvest per man day was 0.83 birds per man day, and 7.66 hours were required to harvest one bird.
4. All of the birds were bagged by 57.3 per cent of the hunters. Eighty-two sportsmen harvested daily limits of ducks.
5. Crippling loss amounted to 20.9 per cent, or for every four birds brought to bag, one was unretrieved.
6. Blind success varied from 12 to 174 waterfowl per blind. The type of hunter, his ability, and equipment were apparently the basic cause of the variance. Cover seemed to have little effect on the individual blind success. The success of the parties hunting in the five blinds along the south shore was lower than that of the other parties. Activity along the gravel road running parallel to the south shore may have been responsible for the lower success.
8. The area was not fully utilized. The area had reservation space for 2,625 men during the season plus those that might hunt after blinds were vacated during the day. Use of the area in 1950 amounted to 64.9 per cent of the reservation capacity.

9. Of 875 reservations issued, 382 or 56.3 per cent used them; 318 other parties were accommodated without making previous appointments.
10. The hunters resided in 20 counties of Iowa and 2 cities of Nebraska. Council Bluffs, Iowa, contributed 58.2 per cent of the hunters.
11. A statistical analysis revealed that an increase in the number of hunters did not result in a significant increase in the total daily harvest.
12. Of 235 parties questioned, 211 (89.2 per cent) were satisfied with the way the area was being managed. Only two (0.9 per cent) of the 235 parties saw no type of improvement over the old system of uncontrolled hunting. Of 202 parties, 175 (86.6 per cent) were in favor of the area remaining controlled.
13. The two greatest complaints of the hunters concerned "sky shooting" and defects of the blinds. Of 130 parties asked if they had noticed sky shooting, 98 (75.4 per cent) complained that it had affected their harvest, 26 (20.0 per cent) noticed some sky shooting but thought that the controlled area had decreased it as compared with former years, and 6 (4.6 per cent) noticed none. Of 199 parties commenting on the blinds, 109 (55.2 per cent) were satisfied with them. The remaining 90 had a variety of complaints.
14. The total cost of the project to the Conservation Commission was $2,415.37. This represents a cost of $1.41 per hunter. A fee of 50 cents per person per day will be charged in 1951, which should completely defray the cost of managing and operating the area.

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ON THE PROPERTIES OF VITAMIN B_{12r}

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The catalytic hydrogenation of vitamin B_{12} and oxidation of the brown reduced material with air yields a red material which has been designated B_{12a} (1). The present investigation deals with some properties of the brown, catalytic hydrogenation product which we refer to as B_{12r}. In particular we are interested in the valence of the cobalt atom of B_{12r}, the quantitative aspects of its oxidation to B_{12a}, and its reaction with strong acids, alkalies and complex forming agents. The cobalt atom in vitamin B_{12} is attached to the organic portion of the molecule with a most astonishing firmness. It seemed likely in view of the fact that the complex compounds of bivalent cobalt are much less stable than those of trivalent cobalt, that the cobalt could be extracted from B_{12r}. This hope proved chimerical.

EXPERIMENTAL WORK

Apparatus for Catalytic Hydrogenation

The apparatus shown in Figure 1 was designed so that the hydrogenation could be effected, the catalyst filtered off, and the B_{12r} isolated without contact with air. The reduction was carried out in the following manner. The unit *D* was removed and the sample and solvent were placed in the cell *G*. A small amount of Adams, PtO_2, catalyst was added. The unit at *D* was replaced and the stopcock left in an open position. Stopcocks *A*, *B* and *C* were turned to admit hydrogen gas to tube *K*; stopcocks *E* and *F* were closed so that the gas then bubbled through the solution in cell *G* and passed out at *D*. When the stopcock *F* was opened, hydrogen followed the path through *K* and *L* to flush the cell *I*. The train *H*, *E*, *J* was also flushed with the gas; owing to the pressure drop over the fritted glass filter *J*, this operation was sometimes assisted by applying mild suction at *P*, the cell *I* being stoppered.

After reduction was complete, stopcock *C* was turned to allow the gas to pass into *G* through *M*. By keeping the stopcock *D* open and closing *F*, the pressure of the hydrogen used to push the reduced solution of B_{12} into *H* was controlled with the pressure of a finger on the top of *D*. Under no circumstances was *F* opened while pushing the reduced solution from *G* to *H*, since this allowed the solution to come up through *N* and pass to cell *I* without passing through filter *J*. After the solution had been transferred to *H*, the stopcock at *D* was closed completely and the gas allowed to enter through either *K* or *M*. Stopcock *K* was opened slightly to allow a slow stream of gas to flush *I*, but at the same time

maintaining enough pressure on the solution in *H* to force it through the filter and into *I*.

Once the solution was transferred to *I*, it could be maintained under an inert atmosphere until ready for use by a stream of hydrogen coming through *J*, or by the admission of a stream of nitrogen (oxygen free) through a tube in the stopper of *I*. The gases escaped at the outlet *P*.

PREPARATION OF VITAMIN B_{12r}

Although the hydrogenation of vitamin B_{12} takes place in a simple water solution, it was found that in such a simple solution the platinum

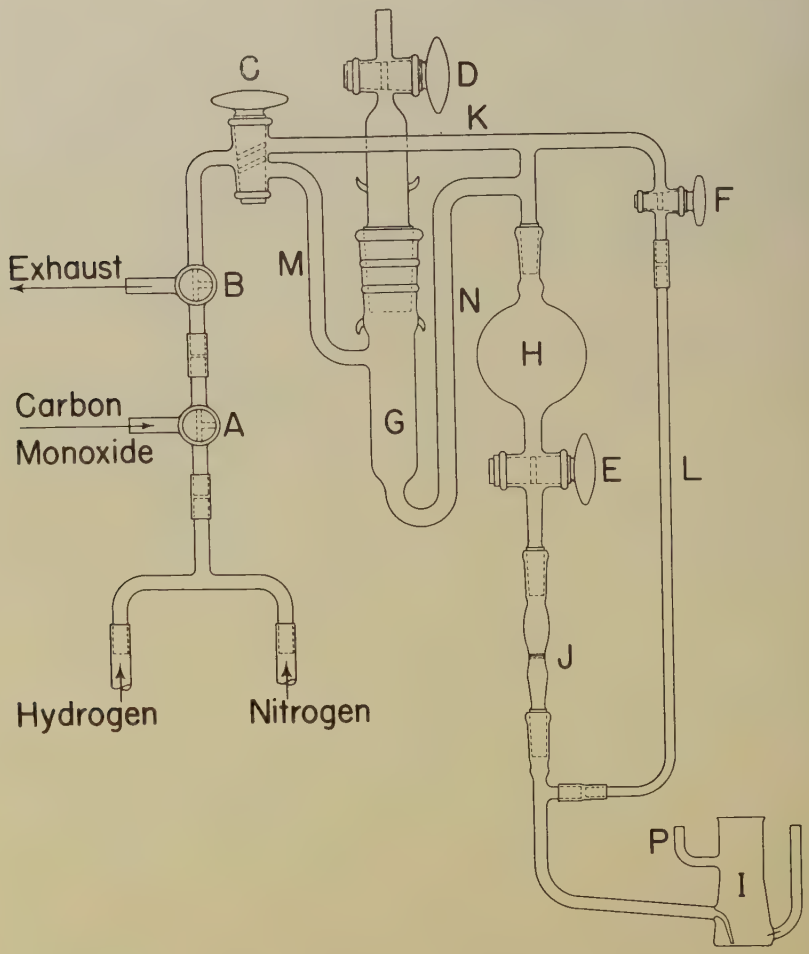

FIG. 1. Apparatus for the Hydrogenation of B_{12} and the Isolation of B_{12r}.

oxide catalyst became colloidal and passed through the fritted glass filter. By carrying out the hydrogenation in 0.1 *N* solution of potassium sulfate, or of potassium chloride, the platinum oxide remained coagulated and was easily filtered. Sulfate was not reduced under these conditions; this was shown by a blank run and titration of the filtrate with permanganate.

The hydrogenation of vitamin B_{12} occurs fairly rapidly at room temperature — usually the passage of hydrogen was continued two to three hours.

The solution of B_{12r}, brown in color, was used for most of the experiments reported later. When necessary the dissolved hydrogen was swept from the solution by a stream of oxygen-free nitrogen. In one experiment the solution of B_{12r} was evaporated to dryness. A non-crystalline mass of brownish-black material was obtained which was subjected to certain treatments.

ABSORPTION SPECTRUM OF B_{12r}

Vitamin B_{12} was hydrogenated in 0.1 *N* solution of potassium sulfate in the apparatus described above. The receiving cell *I* was fitted with a one-hole stopper bearing a pipet which was flushed with nitrogen at the same time the air was swept from the receiving cell. After the B_{12r} solution had been moved to the receiving cell, it was transferred to a quartz, light-absorption cell, previously flushed with oxygen-free nitrogen. Its absorption spectrum was then taken on the Carey automatic spectrophotometer. The absorption curve is shown in Figure 2. B_{12r} has an absorption maximum at 473 mμ and another low maximum at 405 mμ. It has a slight shoulder in the region 348 to 360 mμ where B_{12} and B_{12a}

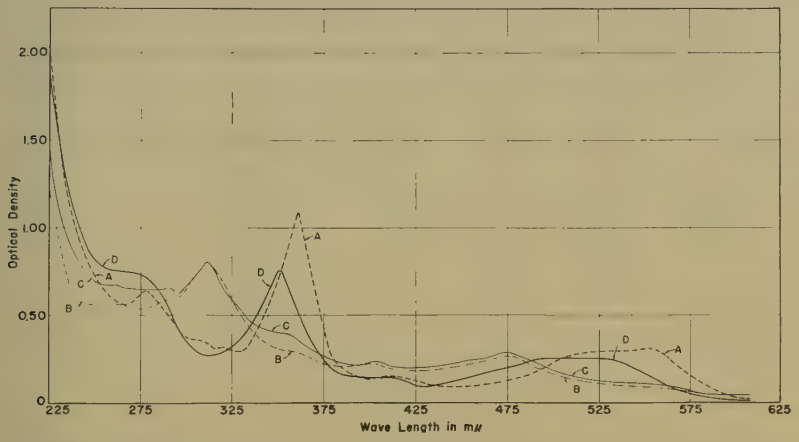

FIG. 2. Absorption Spectra of Vitamins B_{12}, B_{12r}, and B_{12a}. *A*. B_{12}; *B*. B_{12r}; *C*. B_{12r} saturated with carbon monoxide; *D*. B_{12r} saturated with carbon monoxide and then with oxygen (B_{12a}). All solutions at the same concentration in 0.1 *N* potassium sulfate. 1 cm. quartz cell.

TABLE 1

ABSORPTION MAXIMA OF VITAMINS B_{12}, B_{12r}, AND B_{12a}

B_{12}	B_{12r}	B_{12a}
$m\mu$	$m\mu$	$m\mu$
550 low peak	473 peak	500–535 plateau
410 low peak	405 low peak	410 low peak
361 peak	348–355 shoulder	351 peak
278 peak	312.5 peak	

have their principal band. Peculiar to B_{12r} is the intense absorption in the ultra-violet region at 312.5 mμ, a region at which the absorption of B_{12} and B_{12a} is a minimum.

The absorption spectrum of B_{12r} in water changes with time, presumably because of oxidation of the B_{12r} by water.

OXIDIMETRIC TITRATION OF B_{12r}

In the catalytic reduction of Vitamin B_{12} it is assumed that the cyanide group is reduced, presumably to methyl amine, and that the cobalt is reduced also. That the latter is likely, is indicated by the great difference in the absorption spectrum of B_{12r} as contrasted to B_{12} and B_{12a}, and the need of oxygen for the conversion of B_{12r} to B_{12a}. Reduction of B_{12} at the dropping mercury cathode involves two electrons, presumably forming a univalent cobalt compound (2). The present work was undertaken to determine the valence of cobalt in B_{12r}.

Crystalline B_{12}, 5 to 10 mg. in amount, was dissolved in several milliliters of 0.1 *N* potassium chloride and a small amount of platinum oxide catalyst was added. Hydrogen was bubbled through the solution for several hours. The reduction was carried out in the apparatus previously described, Figure 1. When reduction was complete the B_{12r}-potassium chloride solution was forced through the filter by hydrogen pressure into the receiving vessel, *I*. Aliquots of this solution were then taken for potentiometric titration, and spectrophotometric determination of the B_{12a} concentration.

The titration was carried out in a special vessel, Figure 3, designed to accommodate the platinum and saturated calomel electrodes. The solution was stirred magnetically. The potential measurements were made with a Beckman Model G *p*H meter. In the titrations of B_{12r} with potassium ferricyanide, 20 milliliters of phosphate buffer, *p*H 7.4, was placed in the titration vessel and the solution and vessel deaerated by the passage of oxygen-free nitrogen. The B_{12r} solution was then transferred from the receiving vessel, *I*, to the titration vessel using a pipet previously flushed with hydrogen gas. The potassium ferricyanide solution was delivered from a Machlett buret, the ferricyanide solution

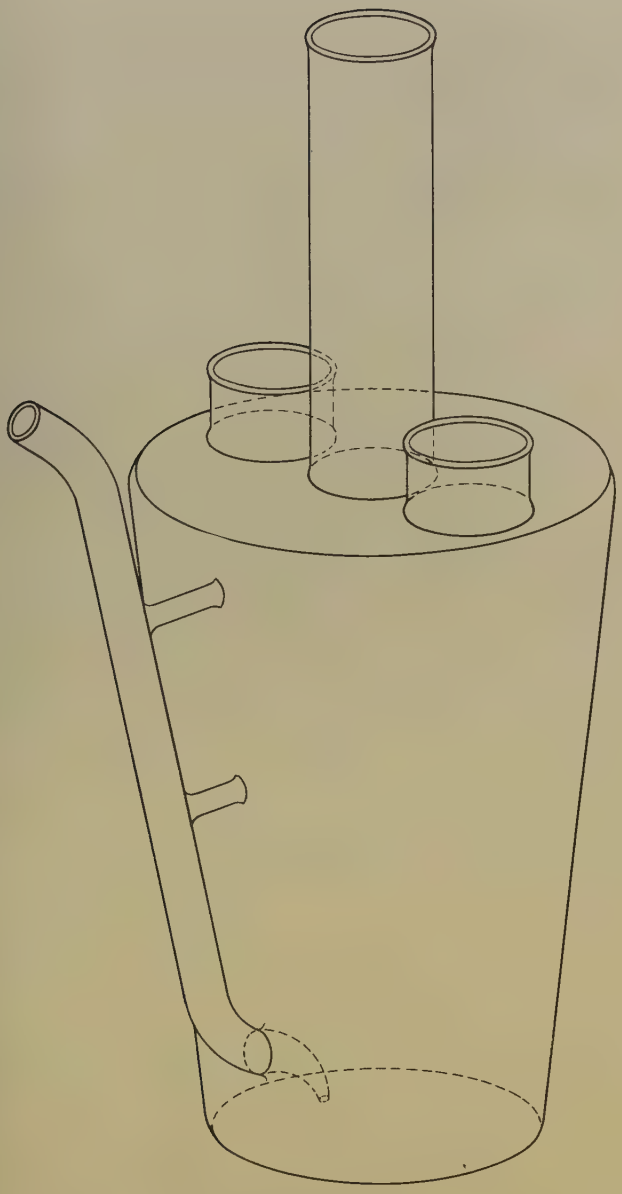

Fig. 3. Titration Vessel

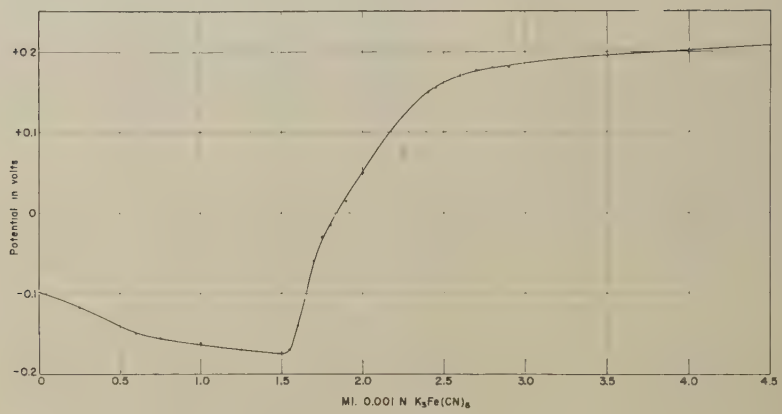

FIG. 4. Titration of B_{12r} with Potassium Ferricyanide. Potential given is that measured against the saturated calomel electrode.

having been previously freed of oxygen by sweeping with oxygen-free nitrogen. The Machlett buret used had a total volume of 5 ml., the smallest division being 0.05 ml.

The concentration of B_{12r} was determined spectrophotometrically by oxidizing an aliquot of the solution with air, diluting suitably with a phosphate buffer, *p*H 7.4, and measuring the optical density at 352.5 mμ. In calculating the results, the value $E^{1\%}_{1\ cm} = 175$, was used.

In the titration shown in Figure 4, the following data were obtained:

Titration

B_{12r} taken	3.00 ml.
$K_3Fe(CN)_6$ used	1.60 ml.
N of K-Fe $(CN)_6$	0.00100

Milliequivalents B_{12r} calculated from these data, 1.60×10^{-3}.

Spectrophotometric Measurement

B_{12r} taken	0.200 ml.
Diluted to	10.00 ml.
Optical Density	0.241 (1 cm. cells)

Milliequivalents B_{12r} calculated from these data, 1.65×10^{-3}.

It is apparent therefore that one equivalent of oxidizing power is required to oxidize B_{12r}.

The color of the solution following the oxidation of B_{12r} with potassium ferricyanide resembles that of B_{12a} formed by air oxidation of B_{12r}. Although the absorption spectrum of the solution was not run because of the expected interference of the ferrocyanide present, it seems safe to assume that the solution contained B_{12a} (as the ferrocyanide). Inasmuch as one equivalent was required for the oxidation, B_{12r} is a bivalent cobalt compound, B_{12a} having been shown to contain trivalent cobalt (2). It is apparent therefore that reduction of B_{12} polarographically and by catalytic hydrogenation achieve quite different results.

ABSORPTION OF OXYGEN BY B_{12r}

A series of experiments was carried out to determine the amount of oxygen taken up by B_{12r} in its conversion to B_{12a}. The Warburg manometric apparatus was used with a specially designed cell to permit introduction of oxygen (Fig. 5).

Crystalline B_{12}, weighing 45 mg. and dissolved in 5.0 ml. of 0.1 *N* potassium sulfate, was hydrogenated over platinum oxide in the apparatus described in Figure 1.

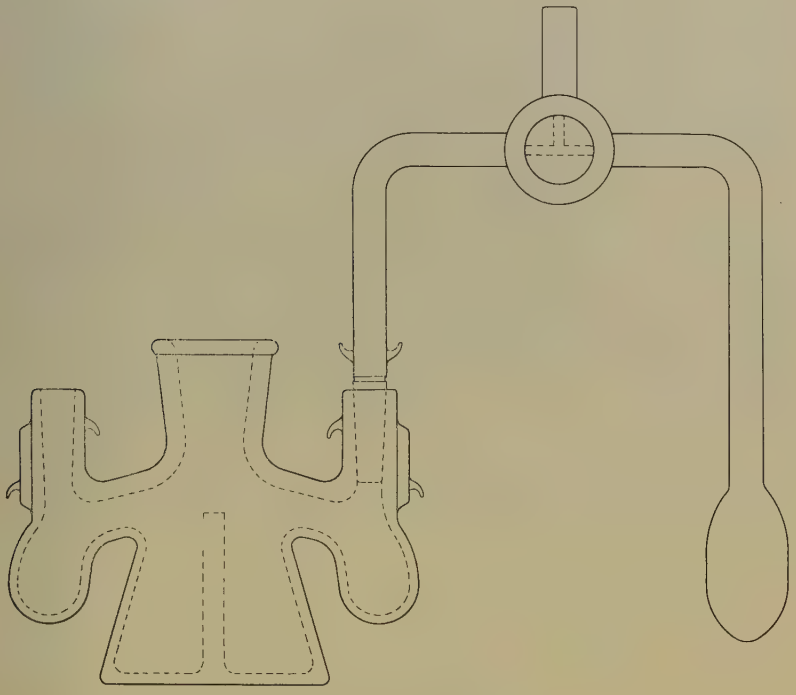

FIG. 5. Modified Warburg Cell.

The bulb attached to the side arm of the Warburg cell was evacuated and filled with pure oxygen. The cell was then attached to the manometer in the usual fashion. Nitrogen, freed of oxygen by passage through a vanadyl sulfate solution, was passed through the apparatus to flush oxygen from the cell and manometer. The cell was immersed in the constant temperature bath at 37.5°, the passage of nitrogen being continued. The freshly prepared B_{12r} solution was transferred from the receiving vessel of the hydrogenation apparatus (Fig. 1) to the side arm of the Warburg vessel with a 2.0 ml. pipet previously flushed with nitrogen. A vigorous stream of nitrogen was passed through the War-

burg cell while this transfer was being made to prevent any diffusion of oxygen into the cell. The system was closed and allowed to come to equilibrium with the constant temperature bath. The B_{12r} solution was then tipped from the side arm into the larger compartment and the stopcock was opened to allow the oxygen in the bulb to diffuse into the main cell and react with the B_{12r}. As usual in work with the Warburg apparatus a similar cell was carried along in identical fashion to serve as a thermobarometer.

In each experiment, there occurred a slight increase in pressure within the cell indicating evolution of gas rather than absorption. During the experiments the brown color of B_{12r} gave way to the red-orange color of B_{12a}. It is possible that B_{12r} reduces water (there is other evidence of this), but the latter experiments of this series were carried out expeditiously to minimize the time between the reduction and the start of the oxygen treatment. It seems unlikely reduction of water and the concomitant evolution of hydrogen could compete with oxidation by oxygen.

ACTION OF CARBON MONOXIDE ON B_{12} AND B_{12r}

The absorption of carbon monoxide by hemoglobin and the relationship of vitamin B_{12} to blood and to hemoglobin makes it of interest to determine if carbon monoxide also reacts with vitamin B_{12}. Theoretically, this might not be expected because the known compounds of cobalt which absorb and release oxygen reversibly do not react with carbon monoxide. Absorption of carbon monoxide, if it does occur, should be by attachment to the cobalt atom and should alter the absorption spectrum.

Carbon monoxide was bubbled through a solution containing about 250 g. per ml. of B_{12}. The absorption spectrum of the solution was taken on the Cary automatic spectrophotometer before and after this treatment. The curves obtained were identical and it was concluded that no reaction had occurred.

Ten mg. of B_{12} dissolved in 0.1 *N* potassium sulfate was reduced catalytically in the apparatus described above. Carbon monoxide, freed of oxygen by passage through fresh alkaline pyrogallol, was passed through the B_{12r} solution in cell *I* for 1.5 hours. A portion of the solution was then transferred by pipet to a 1 cm. quartz cell, previously flushed with nitrogen. The cell was then filled to the neck with 0.1 *N* potassium sulfate which had been swept with hydrogen and carbon monoxide to remove all dissolved oxygen. The absorption spectrum of the solution was taken using the Cary instrument with a 0.1 *N* potassium sulfate solution in the reference cell. Oxygen was then bubbled through the solution and the absorption spectrum taken again.

The curves obtained in this work are reproduced in Figure 2, curves *C* and *D*. There are some differences between the curves of B_{12r} and of B_{12r} treated with carbon monoxide but the absorption maxima and shoulders occur at the same wave lengths and the differences are probably not significant. Oxidation by air gave a curve identical with that of B_{12a}. It was concluded therefore that B_{12r} does not react with carbon monoxide.

THE REACTION OF B_{12r} AND POTASSIUM CYANIDE

So great is the stability of the cobalticyanide ion that the addition of potassium cyanide to bivalent or trivalent cobalt compounds, simple or complex, rapidly extracts the cobalt from them, the oxidation of bivalent cobalt occurring at the expense of water if no other oxidizing agent is present. Vitamin B_{12} is apparently the sole exception to this. The B_{12} molecule possesses exceptional stability and treatment with potassium cyanide fails to pull the cobalt away from the molecule. Rather, there is formed a purple addition compound, $B_{12}CN^-$, bearing one cyanide group in addition to that already present in the molecule (3, 4), which is stable as long as excess cyanide ion is present. That this exceptional behavior of a cobalt compound toward cyanide might not be extended to B_{12r} in which the cobalt is bivalent, prompted the following work.

Crystalline B_{12} was dissolved in 0.1 *N* potassium sulfate and hydrogenated over platinum oxide in the apparatus described above, Figure 1. A solution of potassium cyanide, 1 *M* in strength, was placed in the receiving cell and thoroughly deaerated by passage of hydrogen gas while the hydrogenation proceeded. When reduction was complete, the B_{12r} solution was forced through the filter and into the receiving cell. The purple color of $B_{12}CN^-$ formed instantly upon contact of the B_{12r} solution with the potassium cyanide solution. Working so as to exclude contact with air, the absorption spectrum of the solution was taken on the Carey spectrophotometer. Air was then bubbled through the solution and the spectrum again taken. For comparison the absorption spectrum of an equal amount of B_{12} dissolved in a solution of potassium cyanide was also taken.

The three spectra were identical.

Thus, B_{12r} is such a powerful reducing agent that it is oxidized by potassium cyanide (and then combines with more cyanide to form $B_{12}CN^-$).

ACTION OF CONCENTRATED SULFURIC ACID ON SOLID B_{12r}

Crystalline B_{12} was dissolved in 0.1 *N* potassium sulfate and hydrogenated catalytically in the apparatus described in Figure 1. When reduction was complete the solution was forced through the fritted glass filter and collected in the receiving cell. A stream of dry, oxygen-free nitrogen was directed downward upon the solution and the cell was warmed by radiation from a heat lamp. After several hours all water was vaporized and there remained brown-black, solid B_{12r} and potassium sulfate. This dried material was treated with deaerated, concentrated sulfuric acid. The resulting solution was brown in color resembling other solution of B_{12r}. An aliquot of this solution when diluted with water and exposed to air had the color of B_{12a}. The concentrated sulfuric acid solution was warmed to 80°. An aliquot of this when diluted and oxidized with air appeared to be essentially B_{12a}.

It is apparent, therefore, that the cobalt atom cannot be removed from B_{12} by reduction and treatment with strong acid.

CONCLUSIONS

The absorption spectrum of B_{12r} is markedly different from that of B_{12} and B_{12a}, being characterized by absorption maxima at 473 mμ ($E^{1\%}_{1\ cm.} = 54$), 405 mμ ($E^{1\%}_{1\ cm.} = 43$), and 312.5 mμ ($E^{1\%}_{1\ cm.} = 153$). The absorption spectrum of B_{12r} dissolved in water changes with time.

B_{12r} requires one equivalent for its oxidation to B_{12a} as shown by potentiometric titration in neutral solution with potassium ferricyanide. This undoubtedly is the oxidation of bivalent to trivalent cobalt.

An attempt to measure the volume of gaseous oxygen required to oxidize B_{12r} to B_{12a} failed, a slight evolution of gas being observed during the oxidation of the B_{12r}.

Carbon monoxide is not absorbed by either B_{12} or B_{12r}.

Potassium cyanide converts B_{12r} instantly to the purple $B_{12}CN^-$.

Solid B_{12r} is brownish black in color. Treatment with concentrated sulfuric acid even at 80° does not extract the cobalt from it.

Acknowledgment

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INDENTATION OF A SEMI-INFINITE MEDIUM BY AN AXIALLY SYMMETRIC RIGID PUNCH

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1. Introduction. The main object of this paper is to consider the stresses and strains produced in a semi-infinite isotropic elastic medium when its plane boundary is indented by an axially symmetric rigid punch. J. W. Harding and I. N. Sneddon[1] have shown how to reduce the main part of such problems to the task of solving a pair of dual integral equations. Using this approach, I. N. Sneddon[2],[3] has subsequently given detailed analyses of the stress in the medium when the punch is a flat ended cylinder or a right circular cone. In this paper a similar analysis will be undertaken when the indenting surface is expressible in cylindrical coordinates in the form z = polynomial in r. An interesting feature of the results is that the stress and strain components at any point in the medium are obtainable in closed form in terms of elementary functions. Spherical indentation is given special consideration in the last section. The treatment throughout assumes statical elastic conditions, but, as pointed out by Sneddon in the papers just cited, results obtained in this way can give useful information in certain dynamical situations (e.g., in the theory of armor penetration) if the velocity of the indenting agent is small compared with the velocity of the waves in the medium.

2. The Potential Function Ψ for Three Dimensional Problems with Axial Symmetry. Consider a homogeneous isotropic elastic medium of Young's modulus E and Poisson's ratio σ. Use cylindrical coordinates (r, θ, z) and let the z-axis be an axis of symmetry; then it is known[4] that, in the absence of body forces, the equilibrium equations are satisfied if the stress components are derivable from a potential function $\Psi(r,z)$ as follows:

$$\tau_{rr} = \sigma \nabla^2 \psi_z - \psi_{rrz}$$

$$\tau_{\theta\theta} = \sigma \nabla^2 \psi_z - \frac{1}{r} \psi_{rz}$$

$$\tau_{zz} = (2-\sigma) \nabla^2 \psi_z - \psi_{zzz} \qquad [1]$$

$$\tau_{rz} = \frac{\partial}{\partial r} \left[(1-\sigma) \nabla^2 \psi - \psi_{zz} \right]$$

where the subscripts on ψ denote partial derivatives. (The other two stress components vanish identically.) Of the six compatibility relations, two are automatically satisfied, and the remaining four are also satisfied if

$$\nabla^4 \psi = 0. \qquad [2]$$

The displacement components will then be given by

$$2Gu_r = - \psi_{rz}$$

$$2Gu_z = 2(1-\sigma) \nabla^2 \psi - \psi_{zz} \qquad [3]$$

where $2G = E / (1 + \sigma)$.

3. Boundary Conditions. Suppose that the boundary of the medium is the plane $z = 0$ and that the z-axis is directed into the medium. Consider a rigid punch which is in contact with the medium over the region $r < a$ and let the equation of the surface of contact be $z = g(r)$ where $g(r)$ is the polynomial $A_0 + A_1 r + A_2 r^2 + \cdots + A_n r^n$. The boundary conditions to be met are:

$$\left[\tau_{rz} \right]_{z=0} = 0 \text{ for all } r \geqslant 0 \qquad [4]$$

$$\left[u_z \right]_{z=0} = g(r) \text{ for } r \leqslant a \qquad [5]$$

$$\left[\tau_{zz} \right]_{z=0} = 0 \text{ for } r > a \qquad [6]$$

together with the vanishing of all stress and displacement components at infinity. [7]

From [1] and [3] it is seen that these boundary conditions are restrictions on ψ so that the problem being considered is essentially solved if a biharmonic function $\psi(r,z)$ is found which satisfies [4] - [7].

4. The Equivalent Dual Integral Equations. Fuller details of the material in this section are contained in Harding and Sneddon's paper[1].

Suppose $\psi(r,z)$ is the solution of the problem just stated and let $\overline{\psi}(p,z)$ be its zero order Hankel transform, namely,

$$\overline{\psi}(p,z) = \int_0^\infty r\psi(r,z) J_0(pr) dr.$$

Since ψ is biharmonic it can readily be shown that $\overline{\psi}$ must satisfy the equation

$$\left(\frac{\partial^2}{\partial z^2} - p^2 \right)^2 \overline{\psi}(p,z) = 0.$$

The conditions on ψ at infinity and the boundary condition [4] then require that $\bar{\psi}$ have the form

$$\bar{\psi}(p,z) = F(p)\,(2\sigma + pz)e^{-pz} \qquad [8]$$

Now write $f(ap) = (ap)^4 F(p)$ and let $\rho = r/a$; then it can be shown that the remaining two boundary conditions require that f satisfy the dual integral equations

$$\int_0^\infty t^{-1} f(t)\, J_0(\rho t)dt = -\frac{Ga^4}{1-\sigma}\left[g(a\rho)\right] = h(\rho), \quad \rho \leqslant 1$$
$$\int_0^\infty f(t)\, J_0(\rho t)dt = 0, \qquad \rho > 1. \qquad [9]$$

The problem is thereby reduced to the solution of these dual equations; once f is known then $\bar{\psi}$ is known and ψ can then be determined by using the Hankel inversion theorem. However, by taking the zero or first order Hankel transforms of [1] and later applying the inversion theorem it can be shown that the stress and displacement components are derivable from $\bar{\psi}$ by the formulas:

$$\begin{aligned}
\tau_{rr} &= \int_0^\infty \left[\sigma p\bar{\psi}''' + (1-\sigma)p^3\bar{\psi}'\right] J_0(pr)dp - \frac{1}{r}\int_0^\infty p^2\bar{\psi}' J_1(pr)dp \\
\tau_{\theta\theta} &= \int_0^\infty \left[\sigma p\bar{\psi}''' - \sigma p^3\bar{\psi}'\right] J_0(pr)dp + \frac{1}{r}\int_0^\infty p^2\bar{\psi}' J_1(pr)dp \\
\tau_{zz} &= \int_0^\infty \left[p(1-\sigma)\bar{\psi}''' - (2-\sigma)p^3\bar{\psi}'\right] J_0(pr)dp \\
\tau_{rz} &= \int_0^\infty \left[\sigma p^2\bar{\psi}'' + (1-\sigma)p^4\bar{\psi}\right] J_1(pr)dp \qquad [10] \\
2Gu_r &= \int_0^\infty p^2\bar{\psi}' J_1(pr)dp \\
2Gu_z &= \int_0^\infty \left[(1-2\sigma)p\bar{\psi}'' - 2(1-\sigma)p^3\bar{\psi}\right] J_0(pr)dp
\end{aligned}$$

where primes denote partial derivatives with respect to z.

5. Solution of the Dual Integral Equations. The dual equations [9] are of the type considered by E. C. Titchmarsh[5] and I. W. Busbridge[6] and have the explicit solution

$$f(t) = (2/\pi)^{\frac{1}{2}}\left[t^{\frac{1}{2}} J_{\frac{1}{2}}(t)\int_0^1 y\,(1-y^2)^{-\frac{1}{2}}h(y)dy + \int_0^1 du \int_0^1 u(1-u^2)^{-\frac{1}{2}} h(yu)(ty)^{\frac{1}{2}} J_{\frac{1}{2}}(ty)dy\right]. \qquad [11]$$

If h(r) is a polynomial, as it will be in the sequel, then the solution for f can be written

$$f(t) = \frac{-Ea^4}{\pi(1-\sigma^2)}\left[A_0 f_0(t) + A_1 a f_1(t) + A_2 a^2 f_2(t) + \cdots\right] \qquad [12]$$

where

$$f_0(t) = \sin t$$

$$f_1(t) = \frac{\pi}{2}\left(\sin t - \frac{1-\cos t}{t}\right)$$

$$f_2(t) = 2\sin t + \frac{4\cos t}{t} - \frac{4\sin t}{t^2} \qquad [13]$$

$$f_3(t) = \frac{3\pi}{4}\left[\sin t + \frac{3\cos t}{t} - \frac{6\sin t}{t^2} + \frac{6(1-\cos t)}{t^3}\right]$$

$$f_4(t) = \frac{8}{3}\left[\sin t + \frac{4\cos t}{t} - \frac{12\sin t}{t^2} - \frac{24\cos t}{t^3} + \frac{24\sin t}{t^4}\right]$$

Now split off the first term in the expression of each $f_i(t)$ and denote the sum of the remaining terms by $\phi_i(t)$; that is, let

$$f_1(t) = \tfrac{1}{2}\pi \sin t + \phi_1(t) \text{ etc.} \qquad [14]$$

Hence

$$\phi_1(t) = -\frac{\pi}{2}\frac{(1-\cos t)}{t}$$

$$\phi_2(t) = \frac{-4(1-\cos t)}{t} + \frac{4(t-\sin t)}{t^2} \qquad [15]$$

$$\phi_3(t) = \frac{-9\pi}{4}\frac{(1-\cos t)}{t} + \frac{9\pi}{2}\frac{(t-\sin t)}{t^2} + \frac{9\pi}{2}\frac{(1-\frac{1}{2}t^2-\cos t)}{t^3}$$

$$\phi_4(t) = \frac{-32}{3}\frac{(1-\cos t)}{t} + 32\frac{(t-\sin t}{t^2} + 64\frac{(1-\frac{1}{2}t^2-\cos t)}{t^3} - 64\frac{(t-\frac{t^3}{3!}-\sin t)}{t^4}$$

The reason for decomposing the ϕ's in the above manner will be apparent in section 7.

6. Stress and Displacement Components. The results of the previous section together with [8] show that the solution for $\bar{\psi}$ is

$$\bar{\psi} = (2\sigma + \zeta t)e^{-\zeta t}\, t^{-4} f(t)$$

where $t = ap$ and $z = a\zeta$. Hence, using [13] and [14],

$$\bar{\psi} = K(2\sigma + \zeta t)e^{-\zeta t} t^{-4}\left[C \sin t + A_1 a\phi_1(t) + A_2 a^2\phi_2(t) + \cdots\right] \qquad [16]$$

where $K = -E a^4/\pi(1-\sigma^2)$

and

$$C = A_0 + \tfrac{1}{2}\pi A_1 a + 2A_2 a^2 + \tfrac{3}{4}\pi A_3 a^3 + \tfrac{8}{3}A_4 a^4 + \cdots \qquad [17]$$

It will now be shown that C must be zero (unless $A_1 = A_2 = \cdots = 0$). From [10] it follows, on substituting for $\bar{\psi}$ from [16], that

$$a^5\left[\tau_{zz}\right]_{z=0} = K\int_0^\infty \left[C \sin t + A_1 a\phi_1(t) + \cdots\right] J_0(Pt)dt.$$

When $P = 1$, the integral

$$\int_0^\infty \sin t\, J_0(Pt)dt$$

diverges[7]; whereas it will appear in section 7 that the integrals

$$\int_0^\infty \phi_1(t) J_0(Pt)\,dt$$

converge for all values of P. So, if infinite stress values are to be excluded, C must vanish. Therefore

$$A_0 = -\frac{1}{2}\pi A_1 a - 2A_2 a^2 - \frac{3}{4}\pi A_3 a^3 - \frac{8}{3} A_4 a^4 - \cdots \qquad [18]$$

Now $A_1, A_2, \cdots$ are geometrical constants associated with the punch so that this equation [18] determines the depth of penetration at the center, provided a is known.

Since C = 0, equation [16] yields

$$\bar{\psi} = \sum_{n=1}^{n} A_n a^n \bar{\psi}_n$$

where

$$\bar{\psi}_n = K(2\sigma + \zeta t) e^{-\zeta t} t^{-4} \phi_n(t). \qquad [19]$$

It is evident from equations [10] that the operations on $\bar{\psi}$ which yield the stress and displacement are linear. Hence

$$\tau_{ij} = \sum_{n=1}^{n} A_n a^n \tau_{ij}^{(n)} \qquad [20]$$

$$u_i = \sum_{n=1}^{n} A_n a^n u_i^{(n)} \qquad [21]$$

where $\tau_{ij}^{(n)}$, $u_i^{(n)}$ are derived from $\bar{\psi}_n$ in accordance with [10]. Since $\bar{\psi}_n$ is given by [19] the relations [10] lead to

$$\begin{aligned}
\tau_{rr}^{(n)} &= B\left[P_0^{(n)} - \zeta P_1^{(n)} - \frac{1-2\sigma}{\rho} Q_{-1}^{(n)} + \frac{\zeta}{\rho} Q_0^{(n)}\right] \\
\tau_{\theta\theta}^{(n)} &= B\left[2\sigma P_0^{(n)} + \frac{1-2\sigma}{\rho} Q_{-1}^{(n)} - \frac{\zeta}{\rho} Q_0^{(n)}\right] \\
\tau_{zz}^{(n)} &= B\left[P_0^{(n)} + \zeta P_1^{(n)}\right] \\
\tau_{rz}^{(n)} &= B\,\zeta\, Q_1^{(n)} \\
u_r^{(n)} &= H\left[\zeta Q_0^{(n)} - (1-2\sigma) Q_{-1}^{(n)}\right] \\
u_z^{(n)} &= H\left[\zeta P_0^{(n)} + 2(1-\sigma) P_{-1}^{(n)}\right]
\end{aligned} \qquad [22]$$

where

$$B = -E/\pi a(1-\sigma^2), \quad H = 1/\pi(1-\sigma) \qquad [23]$$

and

$$\begin{aligned}
P_s^{(n)} &= \int_0^\infty t^s \phi_n(t) e^{-\zeta t} J_0(Pt)\,dt, \\
Q_s^{(n)} &= \int_0^\infty t^s \phi_n(t) e^{-\zeta t} J_1(Pt)\,dt.
\end{aligned} \qquad [24]$$

7. Evaluation of the Integrals. The relations [22] show that the determination of the stress and displacement components requires, for each n, the evaluation of the six integrals $P_s^{(n)}$, $Q_s^{(n)}$ where s = -1, 0, or 1. In this section it will be seen that these integrals can all be evaluated in closed form in terms of elementary functions of the position coordinates. Explicit answers will be displayed for values of n up to 4 and the method of extending the list will be clear.

It will be found convenient to introduce the functions $R, \alpha, \beta, \cdots$ of the position coordinates ρ, ζ (N.B. $r=a\rho$, $z=a\zeta$) by the following definitions:

$$
\begin{aligned}
R^2 &= \rho^2 + \zeta^2 \qquad (R \geqslant 0) \\
q^2 &= 1 + \zeta^2 \qquad (q \geqslant 1) \\
\cot \alpha &= \zeta \qquad (0 \leqslant \alpha \leqslant \pi/2, \zeta \geqslant 0) \\
s^4 &= (R^2-1)^2 + 4\zeta^2 \qquad (s \geqslant 0) \\
\tan 2\beta &= 2\zeta/(R^2-1) \qquad (0 \leqslant \beta \leqslant \pi/2) \\
\tan \gamma &= \frac{q \sin\alpha + s \sin\beta}{q \cos\alpha + s \cos\beta} \qquad (0 \leqslant \gamma \leqslant \pi/2) \\
w &= \frac{\{q^2+s^2+2qs\cos(\alpha-\beta)\}^{\frac{1}{2}}}{R+\zeta} \qquad (w > 0)
\end{aligned}
\qquad [25]
$$

Clearly the coordinates (r, θ, z) of any point of the medium uniquely determine the corresponding values of $R, q, \alpha, \cdots$ so that it will be satisfactory to evaluate the integrals which arise, in terms of $R, q, \cdots$ as well as ρ, ζ.

From the expressions given for ϕ_i in [15] it is evident that the integrals $P_k^{(n)}$, $Q_k^{(n)}$ are linear combinations of the integrals $C_{mk}^{p}(\rho, \zeta)$, $S_{mk}^{p}(\rho, \zeta)$ defined by

$$
\begin{aligned}
C_{m,k}^{p}(\rho,\zeta) &= \int_0^\infty t^{-k}\left\{1-\frac{t^2}{2!}+\frac{t^4}{4!}-\cdots+(-1)^{m+1}\frac{t^{2m-2}}{(2m-2)!}-\cos t\right\}e^{-\zeta t}J_p(\rho t)\,dt \\
S_{m,k}^{p}(\rho,\zeta) &= \int_0^\infty t^{-k}\left\{t-\frac{t^3}{3!}+\frac{t^5}{5!}-\cdots+(-1)^{m+1}\frac{t^{2m-1}}{(2m-1)!}-\sin t\right\}e^{-\zeta t}J_p(\rho t)\,dt
\end{aligned}
\qquad [26]
$$

where p = 0 or 1 and for each m the associated value of k will always be such as to make the integrals convergent. (Some will diverge for $\zeta = \rho = 0$).

To evaluate the integrals [26] one may start with the well known result[8]

$$\int_0^\infty e^{-at} J_p(bt)\,dt = \frac{\left\{\sqrt{a^2+b^2}-a\right\}^p}{b^p\sqrt{a^2+b^2}}, \qquad \begin{matrix} R(p) > -1 \\ R(a) > |\mathcal{I}\, b| \end{matrix} \qquad [27]$$

This yields, as a special case,

$$\int_0^\infty e^{ikt} e^{-\zeta t} J_0(\rho t)\,dt = \frac{1}{\sqrt{\left\{(\zeta - ik)^2+\rho^2\right\}}} \qquad [28]$$

which is valid for $\zeta > 0$, $\rho \geqslant 0$, $k \geqslant 0$. When $\rho = 0$ a simple independent calculation shows that the right hand side of [28] must reduce to $(\zeta + ik)/(\zeta^2+k^2)$ which represents a point in the positive quadrant of the Argand plane. Hence interpret the radical in [28] to mean $s_k \exp(-i\beta_k)$, where

$$s_k^4 = (R^2 - k^2)^2 + 4\zeta^2 k^2 \quad (s_k > 0)$$

$$\tan 2\beta_k = 2\zeta k/(R^2-k^2) \quad (0 \leqslant \beta_k \leqslant \pi/2),$$

so that

$$\int_0^\infty e^{ikt} e^{-\zeta t} J_0(\rho t)\,dt = s_k^{-1} \exp(i\beta_k), \qquad [29]$$

which shows that the real and imaginary parts of the integral are both positive (or zero) for the range of values of the parameters ρ, k, ζ specified above. Therefore successive integrations of [28] with respect to k between 0 and k must yield a complex number in the positive quadrant of the Argand plane. This observation will serve as a guide in choosing the correct branch of the multi-valued functions which will be used in the computations which follow.

Now the integrand in [28] is a continuous function of (k,t) over the region $t \geqslant 0$, $k \geqslant 0$, and the Cauchy criterion shows that the integral is uniformly convergent (in fact **absolutely-uniformly convergent**) with respect to k over any interval $(0,k')$. Hence [28] may be integrated with respect to k between 0 and k and the order of integration inverted. This gives

$$\int_0^\infty t^{-1}(1-e^{ikt}) e^{-\zeta t} J_0(\rho t)\,dt = \sinh^{-1}\left(\frac{u}{\rho}\right) - \sinh^{-1}\left(\frac{\zeta}{\rho}\right) \qquad [30]$$

where $u = \zeta - ik$. Since the argument in $\sinh^{-1}(u/\rho)$ is complex it is a many-valued function but the method of choosing the correct branch has already been explained. Later, k will be set equal to 1 and it turns out that $\sinh^{-1}\left\{(\zeta - i)/\rho\right\}$ is to be interpreted as

$$\log \frac{\sqrt{\left\{q^2+s^2+2qs\cos(\alpha-\beta)\right\}}}{\rho} - i\gamma$$

where q, s, ··· are defined in [25].

Repeated integrations of [30] with respect to k "under the integral sign" can be justified as above and result in the following:

$$\int_0^\infty t^{-2}(1+ikt-e^{ikt})e^{-\zeta t}J_0(Pt)dt$$

$$= -u\sinh^{-1}(u/P)+u\sinh^{-1}(\zeta/P) + (u^2+P^2)^{\frac{1}{2}} - R \qquad [31]$$

$$\int_0^\infty t^{-3}(1+ikt-\tfrac{1}{2}k^2t^2-e^{ikt})e^{-\zeta t}J_0(Pt)dt$$

$$= \tfrac{1}{4}(2u^2-P^2)\sinh^{-1}(u/P)-\tfrac{3}{4}u(u^2+P^2)^{\frac{1}{2}}+(\tfrac{3}{4}\zeta-ik)R$$

$$+ \tfrac{1}{4}(2k^2-2\zeta^2+P^2+ik\zeta)\sinh^{-1}(\zeta/P) \qquad [32]$$

$$\int_0^\infty t^{-4}(1+ikt-\frac{k^2t^2}{2!}-\frac{ik^3t^3}{3!}-e^{ikt})e^{-\zeta t}J_0(Pt)dt$$

$$= \Big(-\frac{u^3}{6}+\frac{P^2u}{4}\Big)\sinh^{-1}\frac{u}{P}+\frac{11}{36}\Big\{(u^2+P^2)^{\frac{3}{2}}-R^{\frac{3}{2}}\Big\}-\frac{5}{12}P^2\Big\{(u^2+P^2)^{\frac{1}{2}}-R\Big\}$$

$$+\Big(\frac{ik^3}{6}-\frac{\zeta k^2}{2}-i\frac{\zeta^2k}{2}+\frac{iP^2k}{4}+\frac{\zeta^3}{6}-\frac{P^2\zeta}{4}\Big)\sinh^{-1}(\zeta/P)$$

$$+\frac{k^2R}{2}+\frac{3i}{4}\zeta kR \qquad [33]$$

$$\int_0^\infty t^{-5}\Big(1+ikt-\frac{k^2t^2}{2!}-\frac{ik^3t^3}{3!}+\frac{k^4t^4}{4!}-e^{ikt}\Big)e^{-\zeta t}J_0(Pt)dt$$

$$= \Big[\Big(\frac{u^4}{24}-\frac{P^2u^2}{8}+\frac{P^4}{64}\Big)\sinh^{-1}\frac{u}{P}-\frac{u^3}{96}(u^2+P^2)^{\frac{1}{2}}+$$

$$+\Big\{\frac{11P^2}{64}-\frac{11}{144}(u^2+P^2)\Big\}u(u^2+P^2)^{\frac{1}{2}}\Big]_{u=\zeta}^{u=u}+\sinh^{-1}(\zeta/P)\Big(8ik\zeta^3-12ikP^2\zeta$$

$$-2k^4-8ik^3\zeta+12k^2\zeta^2-6P^2k^2\Big)/48$$

$$-\frac{11ikR^3}{36}+\frac{5ikP^2R}{12}+\frac{ik^3R}{6}-\frac{3}{8}\zeta k^2R. \qquad [34]$$

Setting $k = 1$ in equations [29]-[34] and separating real and imaginary parts, one obtains

$$C^0_{1,0} = R^{-1} - (\cos\beta)/s \quad , \qquad C^0_{1,1} = \log w$$

$$C^0_{1,2} = -\zeta\log w + \gamma + s\cos\beta - R$$

$$C^0_{2,2} = C^0_{1,2} - 1/2R \qquad [35]$$

$$C^0_{2,3} = \tfrac{1}{4}\Big\{(2\zeta^2-P^2-2)\log w - 4\zeta\gamma - 3qs\cos(\alpha+\beta)+3\zeta R\Big\}$$

$$C^0_{2,4} = \tfrac{1}{12}(3P^2-2\zeta^2+6)\zeta\log w+\tfrac{\gamma}{12}(6\zeta^2-3P^2-2)+\tfrac{R}{2}+\tfrac{11}{36}(s^3\cos 3\beta-R^3)$$

$$-\tfrac{5}{12}P^2(s\cos\beta-R)$$

$$S^{\circ}_{1,1} = (\rho^2+\zeta^2)^{-\frac{1}{2}}-\gamma,\quad S^{\circ}_{1,2} = \log w + \gamma\zeta - s\sin\beta$$

$$S^{\circ}_{1,3} = -\zeta\log w - \frac{1}{4}\gamma(2\zeta^2-\rho^2-2)+\frac{3}{4}qs\sin(\alpha+\beta)-R$$

$$S^{\circ}_{2,3} = S^{\circ}_{1,3} - 1/6\ R$$

$$S^{\circ}_{2,4} = \frac{\log w}{12}(6\zeta^2-3\rho^2-2)+\frac{\gamma\zeta}{12}(2\zeta^2-3\rho^2-6)+\frac{3R\zeta}{4}-\frac{11}{36}(s^2\sin 3\beta) + \frac{5}{12}\rho^2 s\sin\beta \qquad [36]$$

$$S^{\circ}_{2,5} = (2-2\zeta^2+3\rho^2)\frac{\zeta\log w}{12} - \gamma\left\{\frac{\zeta^4-6\zeta^2+1}{24}-\frac{\rho^2(\zeta^2-1)}{8}+\frac{\rho^4}{64}\right\} - \frac{s}{96}\left\{(1-3\zeta^2)\cos\beta-(\zeta^3-3\zeta)\sin\beta\right\}+\frac{11}{144}\left(s^2q\sin(\alpha+3\beta)\right) - \frac{11}{64}\rho^2 s\,q\sin(\alpha+\beta)-\frac{11}{36}R^2+\frac{5}{12}\rho^2R+\frac{R}{6}.$$

For the corresponding integrals involving the first order Bessel functions a similar procedure can be followed, starting with formula [27] with p = 1, a = ζ - ik, b = P, namely,

$$\rho\int_0^{\infty} e^{ikt}e^{-\zeta t}J_1(\rho t)dt = 1 - u(u^2+\rho^2)^{-\frac{1}{2}} \qquad [37]$$

After successive integrations with respect to k, setting k = 1, and equating real and imaginary parts, one obtains

$$PC^{i}_{1,0} = \frac{q}{s}\left[\cos(\alpha-\beta)\right]-\frac{\zeta}{R},\quad PC^{i}_{1,1} = R - s\cos\beta$$

$$PC^{i}_{1,2} = \frac{1}{2}\left\{qs\cos(\alpha+\beta)+\rho^2\log w-\zeta R+1\right\}$$

$$PC^{i}_{2,2} = PC^{i}_{1,2} - \frac{1}{2}(1-\zeta/R) \qquad [38]$$

$$PC^{i}_{2,3} = \frac{1}{6}\left\{-s^3\cos 3\beta-3\rho^2\zeta\log w+3\rho^2\gamma+3\rho^2 s\cos\beta+R^3-3\rho^2R-3R\right\}$$

$$PC^{i}_{2,4} = \frac{s^3q}{24}\cos(\alpha+3\beta)-\frac{5}{16}\rho^2sq\cos(\alpha+\beta)+\frac{\rho^2}{16}(4\zeta^2-4-\rho^2)\log w - \frac{\rho^2\gamma\zeta}{2}-\frac{R^3\zeta}{24}+\frac{5}{16}\rho^2R\zeta+\frac{R\zeta}{4}-\frac{1}{24}$$

$$PS^{i}_{0,1} = 1 - s\sin\beta$$

$$PS^{i}_{1,2} = R - \frac{1}{2}qs\sin(\alpha+\beta) - \frac{1}{2}\rho^2\gamma \qquad [39]$$

$$PS^{i}_{1,3} = \frac{1}{6}\left\{s^3\sin 3\beta+3\rho^2\gamma\zeta+3\rho^2\log w - 3\rho^2 s\sin\beta-3R\zeta+1\right\}$$

$$PS^{i}_{2,3} = PS^{i}_{1,3} - (1-\zeta/R)/6$$

$$PS^{i}_{2,4} = -\frac{s^3q}{24}\sin(\alpha+3\beta)+\frac{5}{16}\rho^2sq\sin(\alpha+\beta) - \frac{\rho^2\zeta}{2}\log w + \frac{\rho^2\gamma}{16}(\rho^2-4\zeta^2+4)+\frac{R^3}{6}-\frac{\rho^2R}{2}-\frac{R}{6}$$

$$PS^{i}_{2,5} = \frac{s^5}{120}\sin 5\beta-\frac{19}{144}\rho^2s^3\sin 3\beta+\frac{7}{48}\rho^4 s\sin\beta+\left(\frac{3\zeta^2-1}{12}-\frac{\rho^2}{16}\right)\rho^2\log w +$$

$$+\left(\frac{\zeta^2-3}{12}-\frac{\rho^2}{16}\right)\rho^2\zeta\gamma-\frac{R^3\zeta}{24}+\frac{5}{16}\rho^2R\zeta+\frac{R\zeta}{12}-\frac{1}{120}\,.$$

It follows that the integrals $P_j^{(n)}$, $Q_j^{(n)}$ are also known in terms of elementary functions since they are linear combinations of the integrals just determined, viz.,

$$\begin{aligned}
P_j^{(1)} &= -\tfrac{1}{2}\left[\pi\, C^{o}_{1,1-j}\right]\\
P_j^{(2)} &= -4\, C^{o}_{1,1-j}+4\, S^{o}_{1,2-j}\\
P_j^{(3)} &= -\tfrac{9\pi}{4}\, C^{o}_{1,1-j}+\tfrac{9\pi}{2}\, C^{o}_{2,2-j}+\tfrac{9\pi}{2}\, S^{o}_{1,2-j}\\
P_j^{(4)} &= -\tfrac{32}{3}\, C^{o}_{1,1-j}+32 S^{o}_{1,2-j}+64\, C^{o}_{2,2-j}-64\, S^{o}_{2,4-j}
\end{aligned}\qquad [40]$$

with exactly similar expressions for the Q's obtained by replacing the superscript o on the C's and S's by 1.

The stress and displacement components at any point (r,θ,z) of the medium are given explicitly in terms of the P's and Q's in [22] and so the list of integrals [35]-[40] is sufficient to enable one to compute the stress and displacement at any interior point of the medium when $g(r)$ is a polynomial of degree no higher than 4. The list can clearly be extended to cater for polynomials of higher degree.

The determination of the stress etc. on the boundary $z = 0$ requires further consideration since, in the preceding work of this section, it was stipulated that ζ be strictly positive. This condition was used to justify the process of inverting the order of integration and to ensure the convergence of all the integrals that arose. However, the formulas [35]-[39] remain plausible, save possibly for $P = 0$, when one puts $\zeta = 0$ in the integrand and lets $\zeta \longrightarrow +0$ in the right hand members. The validity of the results so obtained can be established by using the following three lemmas (and similar ones involving $J_1(Pt)$):

(i) If $k \geqslant 0$ and $P \neq 0$, then
$$\int_1^\infty t^{-k}e^{-\zeta t}J_0(Pt)\,dt$$
converges uniformly for $0 \leqslant \zeta < \infty$.

(ii) In (i) the condition $P \neq 0$ may be dropped if $k > 1$.

(iii) If $k > \frac{1}{2}$ and $P \neq 0$ then
$$\int_1^\infty t^{-k}\cos t\, e^{-\zeta t}J_0(Pt)\,dt$$
converges uniformly for $0 \leqslant \zeta < \infty$.

Lemma (i) is proved by applying the Abel test for uniform convergence since $t^{-k}e^{-\zeta t}$ is a non-increasing function of t for each ζ $(\geqslant 0)$ and $\int_1^\infty J_0(Pt)\,dt$ is convergent $(P \neq 0)$. Lemmas (ii) and (iii) follow readily on applying the Cauchy criterion for uniform convergence. For the proof of lemma (iii)

the fact that $\int_1^\infty t^{-k} J_0(Pt)dt$ is absolutely convergent for $k > \frac{1}{2}$ is also used.

Now in the equations [35], [36], [38], [39], for a fixed value of $P(\neq 0)$, the integrands are continuous functions of (t, ζ) over the region $0 \leqslant \zeta < \infty$, $0 \leqslant t < \infty$ and the integrals converge uniformly with respect to ζ over the range $0 \leqslant \zeta < \infty$. Hence the integrals are continuous functions of ζ in this range; in particular they are continuous at $\zeta = 0$. Therefore the values of the desired integrals with $\zeta = 0$ are obtained from the above formulas by letting $\zeta \to +0$. (In some cases the restriction $P \neq 0$ is unnecessary). As $\zeta \to +0$ it is found from [25] that

$$\alpha \to \pi/2\,, \quad q \to 1\,, \quad R \to P\,, \quad s \to |P^2 - 1|^{\frac{1}{2}}\,,$$

$$\beta \to \pi/2 \text{ or } 0 \text{ according as } P \lesseqgtr 1,$$

$$\gamma \to \pi/2 \text{ or } \sin^{-1}(1/P) \text{ according as } P \lesseqgtr 1,$$

$$\log w \to \cosh^{-1}(1/P) \text{ or } 0 \text{ according as } P \lesseqgtr 1.$$

Hence, on letting $\zeta \to +0$ in [35] - [39], one obtains

$$C^{\pi}_{1,1}(P,0) = \begin{cases} \cosh^{-1}(1/P)\,, & 0 < P \leqslant 1 \\ 0\,, & P > 1 \end{cases}$$

$$C^{0}_{1,2}(P,0) = \begin{cases} \pi/2 - P\,, & P \leqslant 1 \\ \sin^{-1}(1/P) + \sqrt{P^2 - 1} - P\,, & P > 1 \end{cases}$$

$$C^{0}_{2,2}(P,0) = \begin{cases} \pi/2 - P - 1/(2P)\,, & 0 < P \leqslant 1 \\ \sin^{-1}\left(\frac{1}{P}\right) + \sqrt{P^2 - 1} - P - \frac{1}{2P}\,, & P > 1 \end{cases} \qquad [41]$$

$$C^{0}_{2,3}(P,0) = \begin{cases} \frac{1}{4}\left[-(2+P^2)\cosh^{-1}(1/P) + 3(1-P^2)^{\frac{1}{2}}\right], & 0 < P \leqslant 1 \\ 0 \text{ for } P > 1 \end{cases}$$

$$C^{0}_{2,4}(P,0) = \begin{cases} -(2+3P^2)\frac{\pi}{24} + \frac{P}{2} + \frac{P^3}{9}\,, & P \leqslant 1 \\ -\left(\frac{1}{6} + \frac{P^2}{4}\right)\sin^{-1}\left(\frac{1}{P}\right) + \frac{P}{2} + \frac{P^3}{9} - \left(\frac{P^2}{9} + \frac{11}{36}\right)(P^2-1)^{\frac{1}{2}}\,, & P > 1 \end{cases}$$

$$S^{0}_{1,1}(P,0) = \begin{cases} P^{-1} - \pi/2 & P \leqslant 1 \\ P^{-1} - \sin^{-1}(1/P) & P > 1 \end{cases}$$

$$S^{0}_{1,2}(P,0) = \begin{cases} \cosh^{-1}(1/P) - (1-P^2)^{\frac{1}{2}}\,, & 0 < P \leqslant 1 \\ 0\,, & P > 1 \end{cases}$$

$$S^{0}_{1,3}(P,0) = \begin{cases} \frac{\pi}{8}(2+P^2) - P\,, & P \leqslant 1 \\ \frac{1}{4}(2+P^2)\sin^{-1}(1/P) + \frac{3}{4}\sqrt{P^2-1} - P\,, & P > 1 \end{cases} \qquad [42]$$

$$S^{0}_{2,3}(P,0) = S^{0}_{1,3} - 1/(6P)\,, \quad (P \neq 0)$$

$$S^{0}_{2,4}(P,0) = \begin{cases} -\left(\frac{1}{6} + \frac{P^2}{4}\right)\cosh^{-1}(1/P) + \left(\frac{11}{36} + \frac{P^2}{9}\right)(1-P^2)^{\frac{1}{2}}\,, & 0 < P \leqslant 1 \\ 0\,, & P > 1 \end{cases}$$

$$S^0_{2,5}(P,0) = \begin{cases} \frac{P}{6} + \frac{P^3}{9} - \pi\left(\frac{1}{48} + \frac{P^2}{16} + \frac{P^4}{128}\right) & , \quad P \leqslant 1 \\ -\left(\frac{1}{24} + \frac{P^2}{8} + \frac{P^4}{64}\right)\sin^{-1}\left(\frac{1}{P}\right) - \frac{(P^2-1)^{\frac{1}{2}}}{96} + \frac{11}{144}(P^2-1)^{\frac{3}{2}} & \\ \qquad - \frac{11}{64}P^2\sqrt{P^2-1} + \frac{P^3}{9} + \frac{P}{6}, & P > 1 \end{cases}$$

$$C^1_{1,1}(P,0) = \begin{cases} 1 & , \quad P \leqslant 1 \\ 1 - (1-P^{-2})^{\frac{1}{2}} & , \quad P > 1 \end{cases}$$

$$C^1_{1,2}(P,0) = \begin{cases} \left[1 + P^2\cosh^{-1}(1/P) - \sqrt{1-P^2}\right]/2P & , \quad 0 < P \leqslant 1 \\ 1/2P & , \quad P > 1 \end{cases} \qquad [43]$$

$$C^1_{2,2}(P,0) = \begin{cases} \frac{1}{2}\left[P\cosh^{-1}(1/P) - (P^{-2}-1)^{\frac{1}{2}}\right] & , \quad 0 < P \leqslant 1 \\ 0 & , \quad P > 1 \end{cases} \qquad [43]$$

$$C^1_{2,3}(P,0) = \begin{cases} P\frac{\pi}{4} - \frac{P^2}{3} - \frac{1}{2} & , \quad P \leqslant 1 \\ -\frac{(P^2-1)^{\frac{3}{2}}}{6P} + \frac{P}{2}\left(\sin^{-1}(1/P) + \sqrt{P^2-1}\right) - \frac{P^2}{3} - \frac{1}{2}, & P > 1 \end{cases}$$

$$C^1_{2,4}(P,0) = \begin{cases} \frac{(1-P^2)^{\frac{3}{2}}}{24P} + \frac{5}{16}P(1-P^2)^{\frac{1}{2}} - \frac{P}{16}(4+P^2)\cosh^{-1}\left(\frac{1}{P}\right) - \frac{1}{24P} & , \quad 0 < P < 1 \\ -\frac{1}{24P} & , \quad P > 1 \end{cases}$$

$$S^1_{0,1}(P,0) = \begin{cases} \left(1 - \sqrt{1-P^2}\right)/P & , \quad 0 < P \leqslant 1 \\ 1/P & , \quad P > 1 \end{cases}$$

$$S^1_{1,2}(P,0) = \begin{cases} 1 - \pi P/4 & , \quad P \leqslant 1 \\ 1 - \frac{1}{2}P\sin^{-1}(1/P) - \frac{1}{2}(1-P^{-2})^{\frac{1}{2}} & , \quad P > 1 \end{cases}$$

$$S^1_{1,3}(P,0) = \begin{cases} \frac{1}{6P}\left[1 - 3P^2(1-P^2)^{1/2} + 3P^2\cosh^{-1}(1/P) - (1-P^2)^{3/2}\right], & 0 < P \leqslant 1 \\ 1/6P & , \quad P > 1 \end{cases} \qquad [44]$$

$$S^1_{2,3}(P,0) = S^1_{1,3} - 1/6P$$

$$S^1_{2,4}(P,0) = \begin{cases} \frac{P(4+P^2)\pi}{32} - \frac{P^2}{3} - \frac{1}{6}, & P \leqslant 1 \\ -\frac{1}{6} - \frac{P^2}{8} + \left(\frac{P}{4} + \frac{P^3}{16}\right)\sin^{-1}(1/P) + \frac{5}{16}P(P^2-1)^{1/2} & \\ \qquad - \frac{(P^2-1)^{3/2}}{24P}, & P > 1 \end{cases}$$

$$S^1_{2,5}(P,0) = \begin{cases} \frac{(1-P^2)^{5/2}}{120P} + \frac{19P}{144}(1-P^2)^{3/2} + \frac{7}{48}P^3(1-P^2)^{1/2} & \\ \qquad - \left(\frac{P}{12} + \frac{P^3}{16}\right)\cosh^{-1}\left(\frac{1}{P}\right) - \frac{1}{120P}, & 0 < P \leqslant 1 \\ -\frac{1}{120P}, & P > 1. \end{cases}$$

Some of these integrals $C^p_{1,j}(P,0)$, $S^p_{1,j}(P,0)$ are divergent at $P = 0$ but it is found that the linear combinations which give the stress and displacement are finite and continuous at the origin. Therefore,

for the cases under consideration, the stress and displacement can be computed at any point of the medium by using the integrals displayed in equations [35]-[44] and the results are in finite closed form involving only elementary functions. The important quantity "a" can be determined by equating the total load to the integral of τ_{zz} over the circle $r \leqslant a$; this will be illustrated in the next section for the case of a sphere.

8. Spherical Indentation. Consider now the case where the surface of contact is spherical, the radius being c. Since the preceding theory assumes that the displacements are small the equation of the sphere may be approximated by

$$z = A_0 + A_2 r^2 + A_4 r^4$$

where $A_2 = -1/2c$ and $A_4 = -1/8c^3$. (A cruder approximation which suffices for many purposes is obtained by taking $A_4 = 0$.) Hence

$$\tau_{ij} = A_2 a^2 \tau_{ij}^{(2)} + A_4 a^4 \tau_{ij}^{(4)}$$

$$u_i = A_2 a^2 u_i^{(2)} + A_4 a^4 u_i^{(4)}$$

where $\tau_{ij}^{(2)}$, $\tau_{ij}^{(4)}$, $u_i^{(2)}$, $u_i^{(4)}$ are determined explicitly from [22], [40] and the list of integrals in section 7. It remains to evaluate a and A_0 in terms of the total load W and the other given constants of the problem.

From [22],

$$\tau_{zz}^{(n)}(\rho,0) = \frac{-E}{\pi a(1-\sigma^2)} P_0^{(n)}(\rho,0)$$

and by using [40]-[42] one finds that, for $\rho \leqslant 1$,

$$P_0^{(2)}(\rho,0) = -4\,(1-\rho^2)^{1/2}$$

$$P_0^{(4)}(\rho,0) = -\frac{32}{9}(1+2\rho^2)(1-\rho^2)^{1/2}.$$

Hence, for $\rho \leqslant 1$,

$$\tau_{zz}(\rho,0) = A_2 a^2 \tau_{zz}^{(2)} + A_4 a^4 \tau_{zz}^{(4)}$$

$$= \frac{-2Ea}{\pi(1-\sigma^2)c}\left\{1+\frac{2a^2}{9c^2}(1+2\rho^2)\right\}(1-\rho^2)^{1/2}. \qquad [45]$$

Now

$$W = -\int_0^1 \left[\tau_{zz}(\rho,0)\right] 2\pi\rho a^2 d\rho$$

and on using [45] this yields, as the equation to determine a,

$$a^3\left(1+\frac{2a^2}{5c^2}\right) = \frac{3c(1-\sigma^2)W}{4E}. \qquad [46]$$

If a is small compared with c, this has the approximate solution

$$a = \left\{\frac{3c(1-\sigma^2)W}{4E}\right\}^{1/3} - \frac{W(1-\sigma^2)}{10Ec} \qquad [47]$$

and so the circle of contact is known.

The maximum depth of penetration is A_0 and is given by [18], namely,

$$A_0 = -2A_2a^2 - \frac{8}{3}A_4a^4 = \frac{a^2}{c} + \frac{a^4}{3c^3}. \qquad [48]$$

If quasi-static conditions are assumed to prevail during the deformation, the work V done in indenting the medium is

$$V = \int_0^{A_0} W dA_0 = \int_0^a W \frac{\partial A_0}{\partial a} da$$
$$= \frac{8Ea^5}{15(1-\sigma^2)c^2}\left(1 + \frac{16a^2}{21c^2} + \frac{4a^4}{27c^4}\right). \qquad [49]$$

The stress components on the axis of symmetry are found to be

$$\tau_{rr}(0,\zeta) = \tau_{\theta\theta}(0,\zeta)$$
$$= \frac{Ea}{\pi(1-\sigma^2)c}\left[2(1+\sigma)(\zeta\cot^{-1}\zeta - 1) + \frac{1}{1+\zeta^2} + \frac{2a^2}{9c^2}\left\{\frac{3}{1+\zeta^2} - (4+2\sigma)(1-3\zeta^2+3\zeta^3\cot^{-1}\zeta)\right\}\right] \qquad [50]$$

$$\tau_{zz}(0,\zeta) = \frac{-Ea}{\pi(1-\sigma^2)c}\left[\frac{2}{1+\zeta^2} - \frac{4a^2}{9c^2}\left\{2 - \frac{3}{1+\zeta^2} + 6\zeta^2(\zeta\cot^{-1}\zeta - 1)\right\}\right] \qquad [51]$$

$$\tau_{rz}(0,\zeta) = 0. \qquad [52]$$

It follows that [50] and [51] give the principal stresses and the maximum shearing stress $\tau_m(z)$ at a depth z below the origin is given by

$$\tau_m(z) = \left|\tau_{rr}(0,\zeta) - \tau_{zz}(0,\zeta)\right| \qquad [53]$$

Suppose now that the terms in a^3/c^3 are negligible (i.e. the sphere is approximated by a paraboloid of revolution); then

$$\tau_m(z) = \frac{Ea}{\pi(1-\sigma^2)c}\left|\frac{3}{1+\zeta^2} + 2(1+\sigma)(\zeta\cot^{-1}\zeta - 1)\right|$$

and this is a maximum when $z = z_0 = a\cot\alpha$, where

$$8(1+\sigma)\alpha = (10 + 4\sigma)\sin 2\alpha - 3\sin 4\alpha.$$

If $\sigma = 0.3$ then $\alpha = 1{\cdot}122\ldots$ and $\cot\alpha = 0{\cdot}481\ldots$
so that the maximum shearing stress occurs at a depth $z_0 = 0{\cdot}481a$ (approx.) below the origin. This is the point at which the material is most likely

to fail in shear. It is of interest to compare this maximum shearing value with stress values at the origin; the approximate results are:

$$\tau_m(z_o) = 3.08\ \tau_m(0)$$

$$= -0.618\ \tau_{zz}(0,0).$$

The author gratefully acknowledges the guidance of Dr. D. L. Holl which led to the preparation of this paper.

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A COMPARISON OF TWO METHODS FOR THE DETERMINATION OF MOISTURE CONTENT IN HEAT PROCESSED BEEF

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The fluid content of meat cells, variously defined as turgidity, moisture content and juiciness, is an important factor in the measurement of the quality of heat processed meat.

The losses occurring in meat during cooking were investigated by Grindley, McCormack and Porter (5) in 1902. They observed the chief loss during cooking was due to the moisture driven out of the meat. They also noted the moisture loss was inversely proportional to the size of the pieces of meat and proportional to the cooking time.

Baker (2), in 1935, studied the effects of boiling and roasting on beef. He reported that the chief changes occurring in meat during cooking were loss of weight (chiefly as moisture) and loss of solubility of the proteins due to heat coagulation.

In 1935 Child and Baldelli (4) cooked 64 paired roasts at 58° C. and 75° C. They found that the percentage of moisture in the press fluid was slightly greater for roasts cooked at the higher temperature.

The variation among different animals of the same grade and among different muscles within the same animal has been found to be significant by Paul *et al.* (9), Ramsbottom *et al.* (10) and Harrison (7). This led to the use of paired muscles from the same animal for comparison of various effects on palatability factors in many research efforts.

Some of the factors of palatability have been summarized by Lowe (8) as tenderness, juiciness, aroma, flavor, texture and color. Many methods have been devised for the measurement of these factors.

In attempts to determine the juiciness of meat and to obtain juice samples for chemical analysis, Child and Baldelli (4) used a machine called the Minnesota pressometer. This machine is motor driven and applies a force of 200 pounds per square inch to a sample of meat and absorbing material (cloth). The weight of fluid pressed out of the meat was determined by the difference in weight of the meat before and after pressing. The composition of the press fluid was determined by analysis of aliquot portions of the absorbing cloth.

In 1934 Hall (6) used the Carver Press for the determination of

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[2] Project No. *1123*. This paper reports research sponsored by the Quartermaster Food and Container Institute for the Armed Forces, and has been assigned number *366* in the series of papers approved for publication. The views or conclusions contained in this report are those of the authors. They are not to be construed as necessarily reflecting the views or endorsement of the Department of Defense.

press fluid. This machine exerted a pressure of 4,000 pounds per square inch on the sample. The expressed juice was collected in a receiver and the volume and weight were recorded. The juice sample was then analyzed for its chemical composition.

Bard and Tischer (3) determined the changes in tenderness, *p*H, drained juice and moisture content of beef shoulder clods resulting from heat processing in #2 cans.

In the course of this work, the moisture content of the processed beef was determined using the vacuum oven in comparison with the Steinlite Model 300 Liquid Cell moisture tester to discover whether the Steinlite Meter, as it is presently used, may be expected to yield results of precision sufficient for work with heat processed beef.

EXPERIMENTAL PROCEDURE

Comparisons between the vacuum oven and the Steinlite moisture meter were made using canner and cutter grade beef clods as experimental units for the two parts of the investigation. In the short processes, eight clods were processed at two temperatures (225 and 240° F.) for times ranging up to 120 minutes, while in the long processes, processing was at 225, 240 and 255° F. for times ranging up to 360 minutes. Duplicate determinations of moisture content after processing were made on each can by each of the two methods. The official method of the A.O.A.C. (1) for the determination of moisture in a vacuum oven was used for comparison. Samples were ground three times in a Hobart Food Chopper equipped with a ⅛-inch plate. Approximately 6 grams of ground meat were accurately weighed on a torsion balance in aluminum drying dishes (7.5 cm. in diameter and 2.5 cm. deep). Drying was for 6 hours at 95–100° C. at a pressure of less than 100 mm. in a vacuum oven. Two determinations were made for each can of meat.

Samples for the Steinlite determination were aliquots of those used for vacuum oven determinations. Ten-gram portions of the ground meat were weighed on a torsion balance to 0.01 gram and mixed in an Osterizer with 100 ml. of Aquafin # 1. The mixture was then filtered to remove solid particles and the filtrate was used for the determination

TABLE 1

AVERAGE VALUES OF MOISTURE CONTENT OF CANNED BEEF TESTED BY TWO METHODS

Temperature (°F.)	Steinlite Process		Vacuum Oven Process	
	Long	Short	Long	Short
	(*Percentage*)	(*Percentage*)	(*Percentage*)	(*Percentage*)
225	67.54	66.03	66.77	65.30
240	68.70	65.14	66.28	65.47
255	69.62	.....	67.29	.....
Average	68.62	65.58	66.78	65.39

of the moisture content. Steinlite readings were converted to per cent moisture by reference to a conversion table provided with the instrument and designed for use in measuring the moisture content of corn.

RESULTS AND DISCUSSION

Duplicate determinations of the moisture content were made for each temperature and each processing time. The average values of these determinations are given in Table 1 for both the long and the short processes and for each processing temperature.

Using the averages of the duplicate determinations, linear regres-

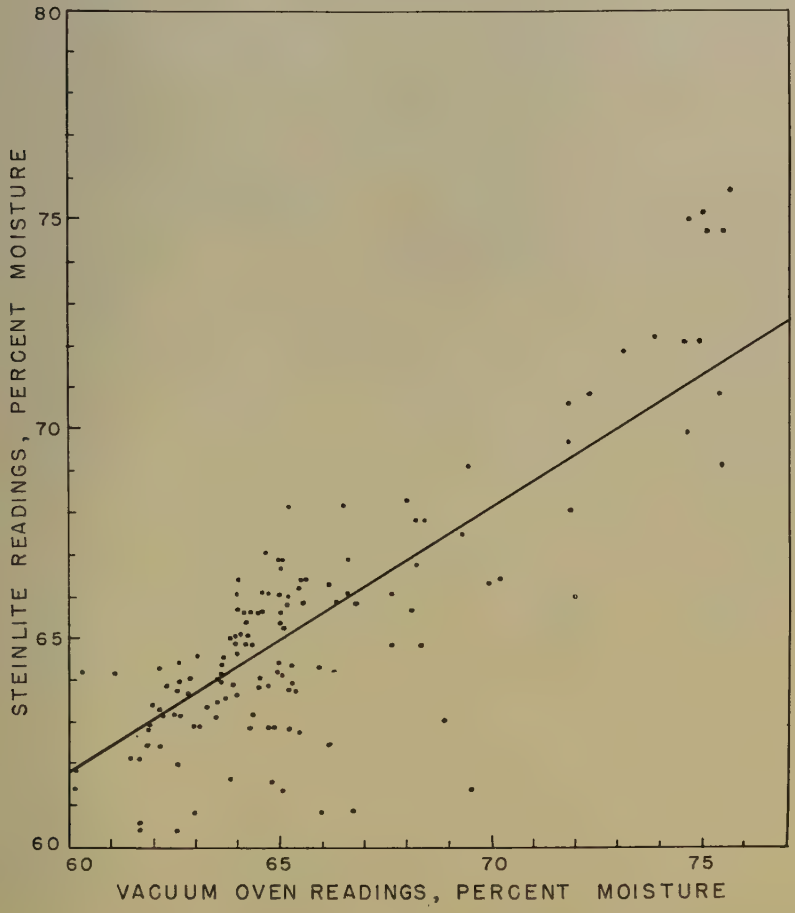

FIG. 1.—Regression of Steinlite readings on vacuum oven readings for the processing temperature of 225°F. SL = 0.70 VO + 20.32.

sions of Steinlite (SL) on vacuum oven (VO) were computed for each processing temperature. For the short process these were SL = 20.32 + 0.70 VO [at 225° F.] and SL = 23.24 + 0.64 VO [at 240° F.] and are shown in Figures 1 and 2 respectively. At 60 per cent moisture content the Steinlite provides estimates about 3 per cent higher than the vacuum oven while, at the higher moisture levels approximating that of fresh meat, the situation is reversed and the Steinlite tester provides estimates which are considerably lower than those obtained with the vacuum oven. This observation is supported by rigorous statistical tests. For both regressions, the intercepts differ significantly from zero and the slopes differ significantly from one. Zero and one are, of

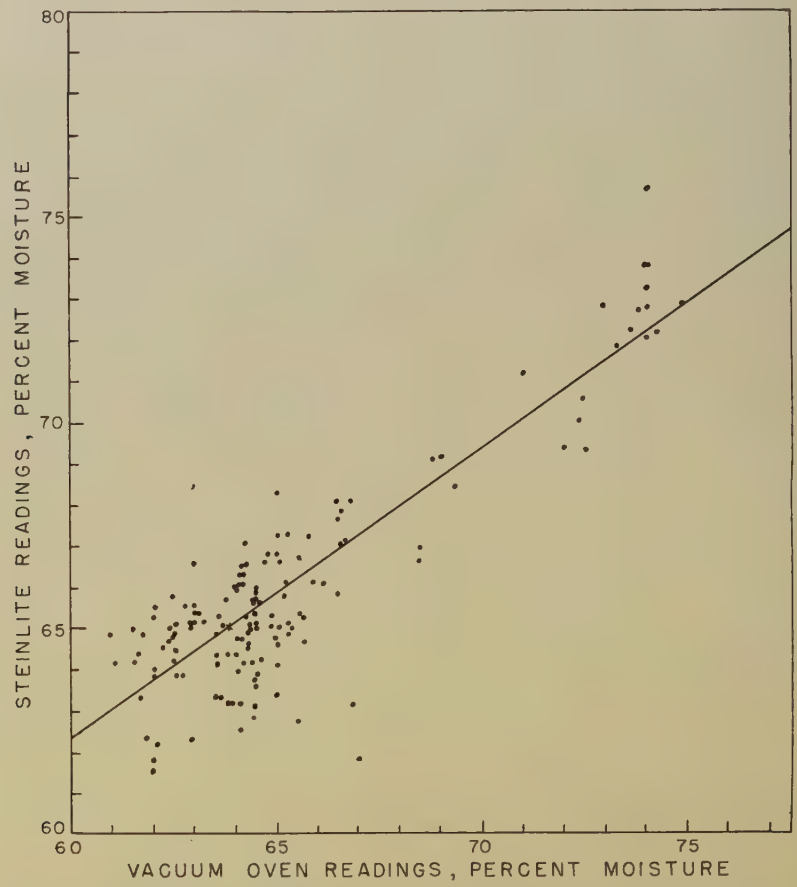

FIG. 2.—Regression of Steinlite readings on vacuum oven readings for the processing temperature of 240°F. SL = 0.64 + 23.24.

course, the values to be expected if the two methods are equivalent. Having concluded that the two methods are not equivalent and if the vacuum oven is used effectively as a standard, it is clear that each Steinlite reading should be corrected through use of an appropriate regression curve relating Steinlite to vacuum oven if it (Steinlite) is to be considered a good measure of moisture content in heat processed beef.[3]

To further emphasize these conclusions regression lines are presented in Figure 3 showing the deviations of the Steinlite readings from the

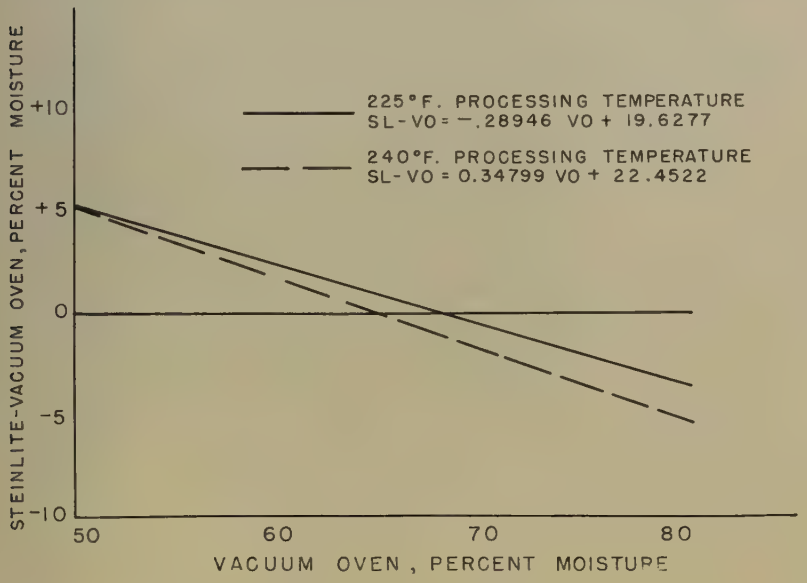

FIG. 3.—Short Process Data.

corresponding vacuum oven readings when plotted against vacuum oven as a standard. Here, the intercepts and the slopes each differ significantly from zero, the expected value if the two methods are equivalent.

Comparisons between the Steinlite moisture tester and the vacuum oven method using canned meat samples from 225, 240 and 255° F. processes ranging in length up to 360 minutes exhibited characteristics similar to those of the short processes (Table 2). The direct comparisons (SL vs. VO) indicate that the two methods are highly correlated, and suggest that the temperature used in processing may also have a discernible effect on the slope and location of the regression line. The

[3] The techniques used assume there are no errors in the "independent" variable, that is, in the vacuum oven measurements. This assumption is not strictly satisfied, but the errors which do occur are such that their effect on the conclusions is negligible.

TABLE 2

Long Process Data. Regressions of Steinlite vs. Vacuum Oven and (Steinlite-Vacuum Oven) vs. Vacuum Oven by Temperature

Processing Tenperature (°F.)	Regression	Correlation
225	SL = 16.7617 + 0.78401 VO	0.9945†
240	SL = 24.0122 + 0.67414 VO	0.9412†
255	SL = 2.3874 + 0.99919 VO	0.9909†
Average of 3 Temperatures	SL = 10.9545 + 0.87221 VO	0.9821†
225	(SL–VO) = 16.7618 + 0.21599 VO	−0.0342†
240	(SL–VO) = 24.0125 + 0.325863 VO	−0.8029†
255	(SL–VO) = 2.3874 + 0.00081 VO	−0.00595
Average of 3 temperatures	(SL–VO) = 10.9545 + 0.12779 VO	−0.6068†

† Significant at the 1 per cent level.

results of the analyses of the 255° F. data suggest that the Steinlite instrument comes into much closer agreement with the vacuum oven when the processing temperature is 255° F. This view is supported by the two regressions SL = 2.3874 + 0.99919 VO and (SL-VO) = 2.3874 + .00081 VO.

SUMMARY

Canner and cutter grade beef shoulder clod cuts were used as replicates in a factorial design to demonstrate the effects of processing temperature, processing time and method of determination on the apparent moisture content of canned meat.

Linear regressions of Steinlite on vacuum oven determinations indicate that the Steinlite tester yields values higher than the vacuum oven when moisture level is low, and yields values lower than the vacuum oven when the moisture level is high. These regressions also suggest that the Steinlite tester comes into closer agreement with the vacuum oven when the processing temperature is 255° F.

The data indicate that, if the Steinlite instrument is to be used to determine the moisture content of processed meat, appropriate regressions or calibration charts designed for meat which take account of the conditions used in processing should be used.

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DETERMINATION OF AMINO NITROGEN IN VITAMINS B_{12} AND B_{12a}

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It has been reported that vitamin B_{12} contains fourteen nitrogen atoms (2). Six of these nitrogen atoms are very weakly basic in character, for they can be titrated in glacial acetic acid solution with perchloric acid (1). The present study was undertaken to determine if any of these nitrogen atoms are present as primary amino nitrogen. The Van Slyke amino nitrogen method was used, in which the volume of nitrogen liberated on reaction of the primary amine with nitrous acid is measured.

EXPERIMENTAL WORK

A commercial Van Slyke micro amino nitrogen apparatus (A. H. Thomas Company) was used in this work.

Solutions of vitamins B_{12} and B_{12a} and purpureo cobaltic chloride, $[Co(NH_3)_5]Cl_2$, were prepared by dissolving the crystalline materials in conductance water.

The concentrations of the vitamins B_{12} and B_{12a} solutions were determined spectrophotometrically using $E^{1\%}_{1\text{ cm.}} = 204$ at 361 mμ for B_{12} and $E^{1\%}_{1\text{ cm.}} = 175$ at 352.5 mμ for B_{12a}.

The vitamin B_{12} and B_{12a} samples used in this work were obtained from E. R. Squibb and Sons, New Brunswick, New Jersey. The purpureo cobaltic chloride used was carefully purified.

The chemicals used in this study were reagent grade sodium nitrite and 99.5 per cent glacial acetic acid. Conductance water was used throughout the entire experiment.

Reagent blanks were run just before each analysis in order to insure proper blank corrections.

Samples of the amino acids glycine and alanine were analyzed to check the operation of the apparatus and the procedure of analysis.

The analyses of vitamins B_{12} and B_{12a} were run in duplicate, the reaction with nitrous acid being continued for five minutes each time. The reagent blanks were reacted the same length of time.

Since there are some types of amino nitrogen such as ammonia which react more slowly with nitrous acid, the analysis of vitamin B_{12} was repeated, increasing the reaction time with nitrous acid to fifteen minutes.

In order to determine whether or not ammonia coordinated to a

TABLE 1

Material	Conc. (mg./ml.)	Sample Vol. (ml.)	Blank (ml. N_2)	Tot. Vol. (ml. N_2)	Net Vol. (ml. N_2)	Reaction Time (min.)	Calc. Vol. for 1 N (ml. N_2)
B_{12}*	8.430	2.000	0.130	0.140	0.010	5	0.350
B_{12}*	8.430	2.000	0.120	0.190	0.070	5	0.350
B_{12a}*	8.150	2.000	0.160	0.220	0.060	5	0.168
B_{12a}†	8.150	2.000	0.160	0.230	0.070	5	0.168
$[Co(NH_3)_5Cl]Cl_2$	3.928	1.000	0.250	0.290	0.040	5	0.409
$[Co(NH_3)_5Cl]Cl_2$	3.928	1.000	0.520	0.490	−0.030	15	0.409
B_{12}*	8.430	2.000	0.440	0.390	−0.050	15	0.339
Glycine†	5.852	1.000	0.170	2.240	2.070	5	2.036
Alanine†	6.344	1.000	0.140	1.840	1.700	5	1.830
Alanine†	6.344	1.000	0.140	1.870	1.730	5	1.830

* Concentration determined spectrophotometrically.
† Concentration determined by direct weighing.

cobalt atom could be determined by this method, a standard solution of the purpureo cobaltic chloride was prepared and a sample reacted with nitrous acid for five minutes and another sample for fifteen minutes.

The results of all of these analyses are summarzied in Table 1.

RESULTS AND CONCLUSIONS

As will be seen from the table, no primary amino nitrogen is present in either vitamin B_{12} or vitamin B_{12a}. Ammonia coordinated to cobalt does not react with nitrous acid as judged from the behavior of one compound. The presence of ammonia coordinated to the cobalt atom of vitamins B_{12} and B_{12a} is therefore not excluded. The two molecules of 1-amino-2-propanol found (3,4) in the hydrochloric acid degradation products of vitamin B_{12} must be attached to the molecule through nitrogen.

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TYPES OF RESPONSE IN INDIVIDUAL DUCKLINGS AND CHICKS TO BLOOD-INDUCED INFECTION WITH *PLASMODIUM LOPHURAE*[1]

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The immunological studies on lophurae malaria in ducklings and chicks which have been conducted in this laboratory for the last four years have provided excellent opportunity to observe marked variability in responses of individual birds with blood-induced infection. A report (1) has been made on the inverse age-resistance exhibited by ducks when mortality was used as the criterion. The effects reported in the present paper are treated topically as follows: (1) survival of the injected parasitized erythrocytes; (2) progress of the infection following transfer of the parasite to the erythrocytes of the injected host; (3) intensity of the parasitemia at the peak and time required; (4) form of the graph of percentage of parasitized erythrocytes against time; (5) duration of parasitemia; (6) relapse; (7) pathogenicity. The study was based on infections in 142 White Pekin ducklings and about 200 New Hampshire chicks purchased when one-day-old from commercial hatcheries.

Transfers of parasitized erythrocytes (P. C.) were both intraspecific (i.e., duck to duck and chicken to chicken) and interspecific (duck to chicken and chicken to duck). The injections were intravenous, and the number of P. C. injected into the birds was uniformly on the basis of body weight within a group, but no attempt was made to maintain uniformity of dosage among the groups. Methods and procedures have been described in previous papers (2, 4, 5). In computing standard deviations actual number of variables was used instead of degrees of freedom.

1. Survival of the Injected Parasitized Cells

For interspecific injections the P. C. were washed three times in the centrifuge with physiological salt solution and suspended in the same as previously described (2). Whole blood generally was used for intraspecific injections.

Destruction of duck P. C. in ducklings. There were under observation 142 White Pekin ducklings 12–19 days old injected with $2x10^8$ duck P. C./100 g. of body weight, composing 23 groups of 4–8 birds each. In

[1] The investigations on which these observations are based were supported (in part) by grants from the Division of Research Grants and Fellowships of the National Institute of Health, United States Public Health Service, and the Industrial Science Research Institute, Iowa State College.

one group of 8 ducklings the mean percentage of P. C. 24 hours after injection was 3.93 ± (s.d.) 1.62; the range, 0.03–6.0 (Table 1). When the count of duck number 36, 0.03, was omitted, the mean percentage of P. C. for the remaining 7 ducklings was 4.49 ± 0.66; the range, 3.8–6.0. The latter figures closely parallel those for another group of 8 ducklings for whom the mean percentage of P. C. was 4.65 ± 0.62 and the range 4.4–5.8. Duckling number 36 was an exceptional individual, for it had not only the lowest count in 142 ducklings 24 hours after injection, but it was 1 of only 2 individuals whose P. C. at the end of the first day was less than the arbitrary figure of one-half the mean of its group. The other low duckling belonged to a group of 5 whose percentages of P. C. by individuals were 1.4, 3.3, 3.4, 3.8, and 4.3; mean, 3.24 ± 0.97.

The 24-hour counts for ducklings injected with duck P. C. showed

TABLE 1

PERCENTAGES OF PARASITIZED CELLS IN A GROUP OF EIGHT 13-DAY-OLD DUCKLINGS INOCULATED WITH *P. lophurae*

	Day of Infection						
	1	2	3	5	6	7	8
Mean of group	3.93	17.2	41	63	61	(1 dead)	(3 dead)
Mean of group less duck No. 36	4.49	19.2	47	71	62	(1 dead)	(2 dead)
Mean of duck No. 36	0.03	0.3	1	10	56	62	(dead)

that while the injected cells were in general well tolerated, there were rare individuals in whom extensive destruction of the introduced cells took place.

Destruction of chicken P. C. in ducklings. The data for two series of ducklings each injected with $1x10^8$ chick P.C./100 g. have been published elsewhere (3). No P. C. were found in the blood smears of one group of 6 control ducklings 17 hours after the injection, but a mean of 0.04 per cent P. C. was found in a group of 12 control ducklings after 24 hours. Two other groups of ducklings were injected with $2x10^8$ chick P. C. After 24 hours no P. C. could be located in smears of one group of 6, and 8 of a group of 10 were negative, but the smears of 2 individuals showed 0.03 per cent P. C.

The observation that blood smears of 28 of a total of 34 ducklings were microscopically negative for P. C. within 24 hours after injection, and the extremely low incidence of P. C. in the 6 positive smears attests to the tremendously rapid destruction of chick P. C. in ducklings; this is quite in contrast to the aforementioned observations on the incidence of P. C. in the blood smears of ducklings 24 hours after the injection of duck P. C. The survival of a modicum of chick P. C. in 6 ducklings

and their apparently complete destruction in 28 others indicates certain individual differences in the injected hosts.

Destruction of chicken P. C. in chicks. A group of 45 13-day-old male chicks was injected with 1.2×10^8 chick P. C./100 g. body weight. The mean percentage of P. C. at 20 hours after injection was 0.89 ± 0.20; range, 0.3–1.3. There were 5 counts of 0.6, which was the next to the lowest. Another group of 30 chicks was injected with 2×10^8 chick P. C. The mean percentage of P. C. at 48 hours after injection was 7.9 ± 2.6; range, 1.5–13.5. All but 7 counts fell within the range 5.5–10.8.

The standard deviations and ranges for these groups speak for the variability in the destruction of the introduced cells that occurred in these two groups. The coefficient of variation $(100 \frac{\text{S. D.}}{\text{M}})$ for the first group was 22.5 per cent; that for the second group, 33.0 per cent.

Destruction of duck P. C. in chicks. The means and standard deviations of the percentage of P. C. in smears of the blood of chicks injected with duck P. C. are exceedingly variable, as an inspection of our published data (2, 4) would reveal. In several groups there were actually no surviving P. C. to be found in the smears after intervals such as 1 hour, 5 hours, or 22 hours. In other groups there were moderately high means of surviving injected P. C., although the variability of the counts, as indicated by the ratio of standard deviations to the means, was comparatively high. In certain groups the standard deviation almost equaled, or even exceeded, the mean. Following are the individual percentages of P. C. 18 hours after injection of an exceedingly variable group of 7 chicks injected with 3.5×10^8 duck P. C./ 100 g. body weight; 0, 0.03, 0.2, 1.5, 3.4, 6.3, and 8.0. The mean was 2.77 ± 3.02 per cent. In this case the standard deviation exceeded the mean.

In other groups the percentages of P. C. are more uniform, like the following group of 6 injected 18 hours previously with 4×10^8 duck P. C.; 3.3, 10.2, 11.2, 12.0, 13.8, and 14.0. The mean was 10.58 ± 4.01 per cent. In this group the standard deviation was much higher than it would otherwise have been because of one low count. In the following counts of a group of 6 chicks injected 30 hours previously with 3×10^8 duck P. C., there was one much higher than the others: 0.0, 0.13, 0.17, 0.27, and 4.7. The last figure probably represents near complete survival of the injected duck P. C. The mean, 0.88 per cent is only half the standard deviation, ± 1.71 per cent.

These data indicate that innate resistance to foreign (duck) P. C. injected into their blood streams varies with the individual chicks, for in certain individuals practically all of the introduced P. C. perish; in others relatively few are destroyed for at least 24 hours, while most of them show varying degrees of resistance between these extremes. It is to be noted that the coefficients of variation are considerably higher than in the case of either ducks injected with duck P. C. or chicks injected with chick P. C.

2. Progress of the Parasite After Transferring to the Host's Own Erythrocytes

Before the end of the second day after injecting the parasitized erythrocytes, schizogony takes place in surviving transfused cells, and surviving merozoites have taken to the new host's own erythrocytes, because the asexual cycle of *P. lophurae* is known to require about 32 hours. Hence, all P. C. noted in the blood on succeeding days would be indicative of the degree of progress of the infection in the new host, save for occasional gametocytes in transfused duck cells which have been noted in chicks after 1, 2, and even 3 days.

Ducklings injected with duck P. C. It is to be noted in Table 1 that the mean parasitemia for the group less duck number 36 mounted rapidly after injection with duck P. C., so that by the end of 5 days it had attained 71 per cent. A check of 142 ducklings injected with $2x10^8$ duck P. C. showed that peaks of 40–90 per cent P. C. were attained in 4, 5, or 6 days, except that in the case of duck number 36 (Table 1) 7 days were required. When the inoculating doses were much lighter, the peaks were, of course, attained later, but the peak ultimately attained by the parasitemia seemed little affected.

It is to be noted in Table 1 that the percentage of P. C. in duck number 36 was but 10 on the fifth day, while at the same time the mean P. C. for the other 7 ducks of the group was 71. The percentage of P. C. for this duck on day 1 had been 0.03, while the mean for the others of its group was 4.49. The percentage of P. C. in duck number 36 increased 2,000-fold by day 7, when it had risen to 62. Thus it can be deduced that the host was not naturally resistant to the parasite.

What is the explanation for the low count in duck number 36 at the end of the first day? There can be only one conclusion: The passaged duck cells, and not the malarial microorganisms, were incompatible with the constitution of the transfused bird, and most of them along with the contained immature schizonts met rather sudden destruction. Since so few introduced parasites survived, the real inoculating dose of P. C. was very small. Despite this initial handicap the infection progressed in intensity until death supervened on the eighth day. Thus it is evident that. taking the destruction of introduced P. C. into consideration, the ducklings in the age range studied (12–19 days) show a high degree of uniformity in their susceptibility to *P. lophurae,* as may be judged by the progress of the infection.

Ducklings injected with chick P. C. It has been stated above that chick P. C. in general experienced a high degree of destruction in the blood stream of ducklings. The peaks ultimately attained in the ducklings injected with chick P. C. were, however, relatively high (3). These observations lend further support to the conclusions in the last paragraph to the effect that it was the introduced cells and not the parasites which were incompatible with the injected bird, and that ducklings in that age range are rather uniformly susceptible to the parasite itself.

Chicks injected with chick P. C. Mention has been made of a group

of 45 male chicks on which counts were made 20 hours after chick P. C. were injected, and of a chick of this group with 0.3 per cent P. C. as compared with a group mean of 0.89 per cent P. C. By the fifth day the parasitemia in this chick had attained 11.3 per cent P. C. at the same time the group mean was 23.4 ± 11.5 per cent P. C., or a 38-fold increase to be compared with the 26-fold increase for the group. Two other similar cases deserve mention. One chick of a group of 5 had 0.3 per cent P. C. on the second day when the other 4 had 4–11 per cent P. C., but the peak of 80 per cent P. C. attained in it on the seventh day exceeded the peaks attained in the others. Another chick was the only one of a group of 5 in which no P. C. could be found in 10,000 red blood cells examined on either the first or the second day. The percentages of P. C. on succeeding days were as follows: day 4, 0.07; day 5, 0.13; day 6, 0.7; day 7, 5.8; day 8, 7.9; day 10, 17.3; day 11, 30.2; day 14, 0. It is apparent that, in these three chicks, the low count at day 1 was not a sound criterion of the host's susceptibility to the parasite.

In certain other cases the course of the infection was abortive, whether the degree of survival reflected in the early counts was low, average, or high. In the same group of 45 13-day-old male chicks mentioned previously was a chick whose infection had an average start, with 0.9 per cent P. C. on the first day. Succeeding percentages of P. C. were as follows: day 2, 1.8; day 4, 5.0; day 5, 3.6; day 6, 0.4; day 7, 0.1; day 8, 0. The mean percentages of P. C. for the entire group on days 5 and 6 were 29.4 and 24.8, respectively. In this case it is apparent that the host's resistance to the parasite was relatively much greater than that of the 3 birds discussed in the preceding paragraph, although in contrast the survival rate of the transfused cells was relatively higher. These selected cases show the varied responses of individual chicks in resistance offered to the injected chick P. C. In addition the deduction may be made that individual chicks differ in their resistance to the parasite's development in their blood streams and that this individual resistance is independent of the amount of destruction undergone by the introduced chick P. C.

Chicks injected with duck P. C. Since we have already published so extensively (2, 4) on chicks injected with duck P. C., let it suffice to state here that the range of individual differences encountered was qualitatively similar to that in chicks injected with chick P. C., though in general the destruction inflicted on the injected P. C. was of considerably greater magnitude.

3. Intensity of the Parasitemia at the Peak and Time Required

The peak attained by the parasitemia during the course of the infection is considered to be one way of measuring the host's susceptibility. When young ducklings were injected with parasitized cells the peaks attained were high and somewhat moderately uniform whether the destruction of the injected P. C. was comparatively small, as ordinarily when duck P. S. are passaged, or great, as ordinarily when chick P. C. are passaged.

The widest variations occurred among chicks, whether inoculated with chick or duck P. C. The peaks of parasitemia attained by individual chicks of the group of 45 13-day-old chicks (44 survivors) injected with chick P. C. ranged from 5–73 percent P. C. The distribution of the peaks by days is recorded in Table 2. Although it is shown that 28 of the infections peaked at the end of five days, and the peaks of 19 of these lay between 21 per cent P. C. and 40 per cent P. C., a considerable number behaved otherwise. Other (smaller) groups displayed either

TABLE 2

PERCENTAGES OF PARASITIZED CELLS AT PEAKS OF 44 INDIVIDUAL INFECTIONS AND DAYS OF INFECTION ON WHICH THE PEAKS OCCURRED

	Percentage of Parasitized Cells at Peak								
Day of Peak	0–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	Total
4	3	1		1					5
5		6	10	9	2	1			28
6		1		2	3	1	1	1	9
7				1		1			2
Total	3	8	10	13	5	3	1	1	44

more or less variability than this group; and the mean of the peaks attained in individual infections averaged considerably higher in some groups, lower in others.

4. Form of the Graph of Percentage of Parasitized Erythrocytes Against Time

This, the number curve, is the daily count, percentage of P. C. (ordinate), plotted against the days of the infection (abscissa). The curves for infections in ducklings and chicks inoculated with $1\text{-}4\times10^8$ duck P. C. and chick P. C./100 g. body weight, respectively, ordinarily peaked on the fifth or sixth day, after a comparatively steep rise, and declined rather sharply until they reached a point near the base line on the eighth to eleventh day. The decline was usually somewhat more precipitous in chicks than in ducklings.

It has been pointed out in the preceding section that, especially in chicks, the density of the parasitemia at the mode varied through relatively wide limits. The base of the curve beyond the mode, or positive skewness, also varied exceedingly but what was most impressive was the finding that the number curve was not infrequently bimodal, even in chicks which, incidentally, develop immunity more readily than ducks. The number curve for duck number 4 of a previous experiment (5) was bimodal, while that for duck number 25 was trimodal, with death occurring at the third mode on the 67th day of the infection.

A most striking example of a bimodal curve is C2 in Figure 1. This chick was inoculated with $4x10^8$ duck P. C. Two hours later the reading

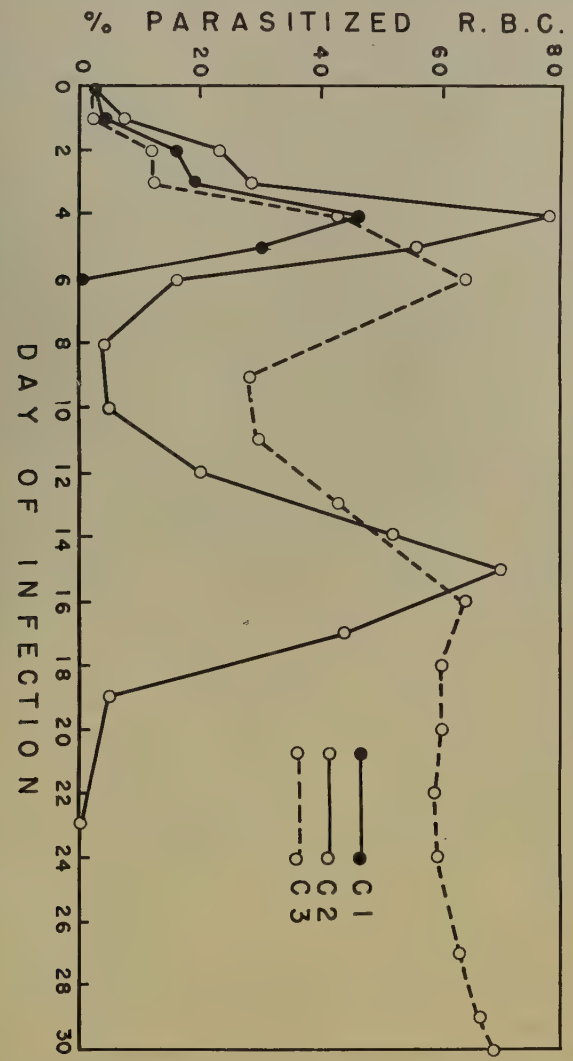

FIG. 1. Number curves depicting course of infection in three female chicks, C1, C2, and C3. C1 attained a moderately high peak, but parasitemia was no longer patent at end of 6 days; C2, of same group as C1, seemed about to recover from parasitemia on 8th day, but relapsed and hit a second peak on 15th day; C3, a chick of another series, did not recover from what appeared to be a second peak of parasitemia on the 16th day.

of the smears showed 2 percent P. C. The parasitemia increased to 78 per cent P. C. at the end of 4 days, declined to 4 per cent P. C. at the end of 8 days, then rose to 70 per cent P. C. at the end of 15 days, and became microscopically non-demonstrable on the 25th day. The curve for another chick of the same group (C1, Fig. 1) and with practically the same count at 2 hours was more nearly "normal," though the infection terminated more abruptly than usually.

5. Duration of the Parasitemia

It is likely that a chick or duckling once inoculated with *P. lophurae* remains infected for the rest of its life, though the parasite may be microscopically demonstrable only at certain times in ducks (5) and (usually) at no time in chicks after it once becomes latent. Only the microscopically demonstrable infection is of concern here. Since ducks' infections are prolonged and tend to relapse (5), only the infections in chicks will be discussed. As a matter of fact, most of the infections in chicks were not followed till they terminated, because it was not necessary to do so to obtain the particular information being sought at the time. In the group of 44 13-day-old male chicks previously mentioned, which were inoculated with 1.2×10^8 chick P. C. and which had a mean count of 0.89 ± 0.20 P. C. at 20 hours, 2 infections terminated after 7 days, 3 after 8 days, 9 after 9 days, 12 after 11 days, and 8 after 13 days. The cumulative total of terminated infections at 13 days, when the last smears were read, was 34. At that time the counts (percentages of P.C.) for the 10 with parasitemia were 0.03, 51.0, 0.1, 0.73, 0.17, 0.07, 0.17, 0.10, 20.50, and 0.3. It is likely that all but 2 of these were about to terminate, and that these 2 were in the process of describing bimodal curves.

The shortest infection observed in chicks was one induced with duck P. C. in which no parasites could be found after the end of the second day. The longest observed in an untreated chick lasted 30 days. It was induced with 4×10^8 duck P. C./100 g. body weight, and the counts (percentages of P. C.) for 10 minutes, 2 hours, and 6 hours were, respectively, 4.1, 3.3, and 2.1. The subsequent course of the infection is shown by C3 in Figure 1. The chick was found dead on the 31st day after surviving parasitemias of 59–69 per cent since the sixteenth day. This chick, a female, died at the age of 46 days. The chick weighed 173 g., less than 0.4 as much as the weight of another recovered female of the same series. Its spleen weighed 0.49 g. and the liver 13.72 g. compared with 2.8 g. and 12.5 g., respectively, for the same organs of the recovered chick. The ratios of spleen and liver to body weight were 0.28 per cent and 7.93 per cent, respectively, compared with 0.58 per cent and 2.63 per cent, respectively, for the recovered chick. The ratio of spleen weight to liver weight was 3.56 percent for the deceased chick and 22.4 percent for the recovered chick. It appears, on the surface at least, that the deceased chick was handicapped by insufficient splenic tissue in its struggle with the parasite, in spite of the fact that its liver underwent compensatory enlargement.

6. Relapse

Ducks surviving the primary attack are prone to relapse and succumb with lophurae malaria (1). If they make complete or near recovery from the primary attack, they will usually relapse, though an occasional duck may not do so. The post-crisis infections in ducks have previously (5) been classified under four types. Chickens are not inclined to relapse. The bimodal number curves previously discussed (C2 and C3 in Figure 1) may be considered to represent one type of relapse, but parasites found in chicks' blood on any day after the parasitemia had once fallen to zero were not only sparse in numbers, but of very rare occurrence.

7. Pathogenicity

As is stated in the preceding paragraph, ducks are prone to succumb with lophurae malaria (1). There are certain rare individuals, however, which survive indefinitely, either because they no longer have demonstrable parasitemia, or because they hold the demonstrable parasitemia to a low level, as did duck number 5 of a previous experiment (5) which died of leucosis at the age of 368 days, still harboring the parasite.

Chicks usually survive the primary infection and become "latent." In the group of 45 13-day-old male chicks mentioned several times previously, there was only one death. There were a few series of 30-40 chicks, ordinarily divided into groups subjected to different treatments, but always with a control group, in which there were no losses by death, while in other series of approximately the same size there were from 1 to 6 deaths from malaria.

DISCUSSION

Todd (7), as a result of hemagglutination tests utilizing serums from a number of individual fowls each injected with the erythrocytes of a particular fowl as iso-antiserum and the erythrocytes of the individual donor birds as antigen, came to the conclusion that a particular iso-antiserum, when tested on the erythrocytes of a number of individuals, may manifest a different degree of activity for the corpuscles of practically each individual. He also declared that, conversely, no two iso-agglutinating serums are identical in their action on the corpuscles of different individuals. He further commented that the rule of individual specificity of red cells is one example of a general rule applying to most of the other cells of the body. The diversity of our findings concerning (1) survival of passaged parasitized cells in the circulating blood, (2) progress of the infection following transfer of the parasite to the red blood corpuscles of the injected host, (3) peaks of parasitemia attained, (4) pattern of the number curve, (5) duration of the parasitemia, (6) relapse, and (7) pathogenicity reflect the many constitutional differences in individuals fully appreciated by Todd.

The innate differences noted in the tolerance of chicks and ducklings

to introduced parasitized erythrocytes from other individuals of the same species were qualitatively almost as wide as they could conceivably have been because, while such transfused hosts were usually moderately to completely tolerant, individuals with different degrees of near-intolerance were not infrequently encountered. The degree of tolerance manifested toward the introduced parasitized erythrocytes in interspecific transfusions was an individual matter, though ducks in general possessed a greater intolerance for parasitized chick cells than did chicks for parasitized duck cells. Chicks exhibited qualitative dfferences in tolerance toward duck erythrocytes almost, but not quite, as wide as toward those of their own species. In certain comparatively few chicks the bulk of the introduced parasitized duck cells survived through 24 hours or longer; in certain others they were almost completely eradicated from the circulating blood within a few hours. There were all degrees of survival between these extremes in most of the chicks, with a tendency for considerably fewer injected cells to survive than when chick cells were injected. The practical importance of ascertaining the tolerance of the host to the introduced parasitized cells is this: the number of parasitized cells injected is not so significant as the number that survive to liberate merozoites which transfer to the cells of the new host.

It was noted that after the parasites transferred to chick erythrocytes, they usually fared exceedingly well whether the passaged parasitized cells were well or poorly tolerated by the host. Usually a high survival rate of introduced parasitized cells gave an immediate impetus to the parasitemia, although in certain cases reproduction lagged after a day or two of development in the host's own cells owing to precocious actively acquired resistance of the host (to the parasite).

Several clinicians have observed that when incompatible malarial blood was injected into the vein of the (human) patient, as for the treatment of paresis, the incubation period of the malarial fever was prolonged to about twice the normal time. Wiener (8) believed that in such individuals hemolysis set free the malarial parasites which then could not develop properly until they had found new host cells. It is, however, exceedingly problematical whether parasites liberated in such a manner were capable of re-entering other blood cells unless they happened to be in the merozoite stage. It is likely that what actually happened was the destruction (by agglutination, phagocytosis, hemolysis, or all three) of all but a residue of the introduced parasitized cells which at the proper time seeded the cells of the new host with merozoites. From then on the parasitemia developed normally, subject only to innate and acquired resistance of the treated individual to the parasite itself.

The value of the peak of parasitemia is another character that exhibits variability, more so in chicks than in ducklings, because there was none of 142 ducklings mentioned above whose parasitemia attained a peak of less than half the group mean. Older ducks that exhibited considerable innate resistance to the development of the parasitemia were,

however, occasionally encountered; for example, the 3 passage ducks previously mentioned (1) whose parasitemia on the fifth day did not exceed 3 per cent, whereas 13 others ranged from 65–90 per cent.

The value of the peak of the parasitemia attained in a particular bird is determined to a considerable extent by actively acquired resistance to the parasite, but the survival of introduced parasitized cells in the blood stream of the recipient is very likely determined by the compatibility of the foreign blood corpuscle with the host's innate resistance mechanism. This was proved by cited instances, among both ducklings and chicks, of very low survival of introduced cells followed in course of time by unusually high parasitemia. Low survival of passaged cells is by no means indicative of high, low, or intermediate peaks in the ensuing parasitemia. Again it should be stressed that the most significant measure of the inoculative dose is not the number of parasitized cells injected, but the percentage of them that survive the destructive impact of the host's defenses until the merozoites have time to develop and transfer to the red blood cells of the injected bird.

The pattern of the number curve was usually very irregular after the eighth or ninth day in ducks that survived the primary infection, and sooner or later there was usually a recrudescence of the infection from surviving parasites regardless of whether they were microscopically demonstrable. The various types of "post-crisis" infections in ducks have previously been delineated (5). Finding that bimodal number curves, of which two of the more extreme types (C2 and C3) are shown in Figure 1, occur not infrequently in chicks is evidence of failure of certain individuals of this species to cope with the parasite so efficiently as the great majority of individuals. The number curve of an unusually resistant chick is designated C1 in Figure 1.

It has been pointed out that the duration of the patent parasitemia is an extremely variable and unpredictable individual host characteristic. The same is true of the pattern of relapse in ducks. Rarely did parasitemia recur in a chick after a period of latency, and when it did recur, it was invariably of a low order.

Chicks and ducklings react quite differently so far as mortality is concerned. It is a general rule that most ducklings die sooner or later with the infection, and most chicks survive. Approximately as many chicks die of lophurae malaria as there are ducks that survive. All our experiments with ducks were done with highly virulent strains of the parasite that had been passaged through ducks at 4-6 day intervals. Death was usually due to anemia resulting from high parasitemia, and the pathogenic effects felt by birds not succumbing varied according to the anemia produced in them.

Bennison and Coatney (6) found that female chicks infected with *Plasmodium gallinaceum* developed significantly higher fourth-day parasitemias than males. In a similar study involving 116 male and 114 female chicks infected with *P. lophurae*, it has not been possible to demonstrate

significant differences between the sexes on any day of the infection. Neither has any significant correlation been found between body weight at injection time and peak of parasitemia.

SUMMARY

Marked differences in the salient characteristics of the parasitemia in ducklings and chicks injected with *Plasmodium lophurae* reflect the individualities of the hosts. Parasitized (with *P. lophurae*) erythrocytes generally undergo from slight to moderate destruction in the blood streams of ducklings injected with duck cells, but in exceptional individuals all but a small residue of them may meet destruction. Parasitized erythrocytes survive well in many chicks injected with chick cells and meet with extensive destruction in a comparative few, but in most chicks they experience varying degrees of mortality between the two extremes.

Parasitized erythrocytes of chicken origin generally suffer high mortality in the blood stream of ducklings, in most of them to the point of near-extinction. The constitutions of chicks, however, exhibit all grades of tolerance to parasitized duck erythrocytes in the blood stream; in certain individuals it appears that all but a modicum of the introduced cells survive, in some they seem to disappear from the circulating blood within a matter of minutes or hours, while in most individuals there are varying intermediate degrees of survival. The destruction of parasitized duck cells in the blood stream of chicks is in general, however, considerably greater than the destruction of parasitized chick cells.

The progress of the parasite after transferring to the erythrocytes of the injected host is independent of the compatibility of the injected blood cells with the duckling or chick host, whether the injected cells be of duck or chicken origin. Whether the destruction of introduced cells is maximum, minimum, or intermediate, the intensity of the parasitemia eventually attained and the time required to attain it depends exclusively on (1) the innate resistance of the host to the parasite itself and (2) the facility with which it can acquire resistance.

Individual ducklings do not show so much variability in respect to the peak attained by the parasitemia and the time required to attain the peak as do individual chicks. In certain individual chicks the height of the peak of parasitemia may be comparable to that attained in most ducklings, but, at the other extreme are those in whom the infection is abortive. The curve of parasitized erythrocytes plotted against time is ordinary monomodal in chicks and ducklings, but at times it is bimodal in chicks, more frequently in ducklings. One trimodal curve was observed in untreated ducklings.

In chicks the microscopically demonstrable parasitemia may last 2 to 31 days, but in most of them the duration is 7 to 13 days. The parasitemia in ducklings usually persists for a long time in the comparatively few individuals that survive the primary attack, and if remission occurs it is usually interrupted sooner or later by reappearance of the parasite. Relapses rarely occur in chicks after the parasites can no longer be found in the blood.

Ducks usually succumb sooner or later to lophurae malaria, for fatal relapses are not infrequent. Most chicks survive the infection, but death occasionally occurs.

The sex of the chick does not seem to significantly affect the intensity of the parasitemia. Neither does the weight of the host at the time of inoculation when the infective doses are graded according to host weight.

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